1988

# Wheat root rot in West Central Morocco and effects of Fusarium culmorum and Helminthosporium sativum seed and soil-borne inoculum on root rot development, plant emergence and crop yield

Abderrahmane Lyamani
*Iowa State University*

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Lyamani, Abderrahmane, Ph.D.

Iowa State University, 1988

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# Wheat root rot in West Central Morocco and effects of *Fusarium culmorum* and *Helminthosporium sativum* seed and soil-borne inoculum on root rot development, plant emergence and crop yield

by

Abderrahmane Lyamani

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
Major: Plant Pathology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1988

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# INTRODUCTION

Root, crown and foot rot of cereals have been a serious problem in the major wheat-producing regions of the world. Several fungi can be involved in the disease complex. These include Fusarium graminearum Schwabe, F. culmorum (W.G. Smith) Sacc., F. avenaceum (Fr.) Sacc., and Helminthosporium sativum Pammel, King, and Bakke. Research in the U.S.A, Canada, England, and Australia has shown that the major root rot pathogens and symptomatology on diseased plants vary greatly worldwide. Annual rainfall and daily temperatures are leading factors in distribution of the disease and its causal agents. While seedling blight is the earliest manifestation of the root rot, death of adult plants, commonly described as whiteheads or deadheads, are the most striking effect of the disease complex. Fusarium graminearum, F. culmorum, and H. sativum are the major pathogens causing cereal root rots, worldwide. These pathogens are both soil and seed-borne.

Although Moroccan plant pathologists and breeders have had the impression that root rot is a serious problem under Moroccan climatic conditions, there has been no accurate information on the causal agents, the sources of inoculum, the impact on yield, or the resistance of commonly-grown

wheat varieties.

The major objectives of the present study were: 1) to determine the importance and cause of root rot in wheat fields in West Central Morocco; 2) to investigate the role of seed and soil as a source of primary inoculum; 3) to investigate the effects of planting density and seed vigor on root rot development; 4) to evaluate the response of commonly grown wheat varieties to the major root rot pathogens; and 5) to determine the effect of Thiabendazole seed treatment on root rot, seedling emergence and crop yield.

# LITERATURE REVIEW

## Symptoms and Host Range

Root rot, crown rot, and foot rot have been used to describe disease conditions of the roots, crown, and base of wheat plant caused by either one or a combination of the pathogenic fungi: Fusarium culmorum, F. graminearum, F. avenaceum (Fr.) Sacc. and Helminthosporium sativum. Rot symptoms may vary from small scattered lesions on the roots to a severe brown decay of the crown and the base (foot).

Fusarium avenaceum (Fr.) Sacc. is in the form-family Tuberculariaceae and is the imperfect stage of Gibberella avenacea Cook. It is worldwide in distribution and causes root rot of wheat, rye, corn, legumes and conifers. It has been reported on plant species in the following host families: Caryophyllaceae, Compositae, Coniferae, Cruciferae, Curcubitaceae, Gramineae, Ericaceae, Euphorbiaceae, Juglandaceae, Lauraceae, Leguminosae, Liliceae, Linaceae, Moraceae, Onagraceae, Palmae, Rosaceae, Rutaceae, Slicaceae, Scrophulariaceae, Solanaceae, Sterculiaceae, Theaceae, Thymeliaceae, Umbelliferae, Valerionaceae and Vitaceae (Booth, 1971).

Fusarium culmorum (W.G. Smith) Sacc. is also in the form-family Tuberculariaceae and is worldwide in its distribution. It causes serious damage to cereals such as wheat, rye, barley, oats, and corn. It has been reported to attack plant species of the following families: Aizoaceae, Betulaceae, Campanulaceae, Caryophyllaceae, Chenopodiaceae, Compositae, Coniferae, Convolvulaceae, Cruciferae, Curcubitacea, Gramineae, Leguminosae, Liliceae, Linaceae, Malvaceae, Musaceae, Palmae, Rosaceae, Saxifragaceae, Solanaceae, Violaceae and Vitaceae (Booth, 1971).

Fusarium graminearum Schwabe belongs to the form-family Tuberculariaceae and is the imperfect stage of Gibberella zeae (Schw.) Petch. It causes seedling blight, root rot, and headblight on wheat and barley and seedling blight, stalk and ear rot, and cob rot on corn. Besides being common on gramineous hosts it is has been also reported on the following plant genera: Coffea, Lycopesicon, Pisum, Trifolium, and Solanum (Booth, 1971).

Helminthosporium sativum is in the form-family Dematiaceae and is the imperfect stage of Cochliobolus sativus (Ito & Kuribayashi) Drechsler ex Dastur. It is common on grasses including barley, oats, rye and wheat and causes leaf spot, seedling blight and root rot (Ellis, 1971).

Root rot is used in this study to designate any necrotic lesions or decay on the underground parts of wheat plants including roots, subcrown internode, crown or the stem base (foot). Symptoms such as seedling blight; stunting; late death of tillers; and premature ripening and bleaching of the ears, commonly known as "deadhead" or "whitehead", occur as a consequence of a severe root rot.

## World Distribution of Root Rot Pathogens

Intensive field surveys of root rot were carried out in Australia, Canada, England, Italy, and the U.S. The pathogens involved and their frequencies were primarily affected by climatic conditions (Broadfoot, 1934b; Burgess et al., 1975; Cook, 1968b).

In the eastern wheat belt of Australia including Queensland, New South Wales, and northern Victoria; F. graminearum was found to be the predominant pathogen associated with root and crown rot of wheat (Wearing and Burgess, 1977; Burgess et al., 1975; Price, 1970; McNight and Hart, 1966; Purss, 1966). Fusarium culmorum and F. avenaceum occasionally were present (Wearing and Burgess, 1977; Burgess et al., 1975). In southern Victoria, however, F. culmorum was the most prevalent species (Chambers, 1972; Sims et al.,

1961).

In England, F. culmorum was dominant in Cambridge area (Russell, 1932), the northern region (Bennett, 1928), Lancashire and Chesire area (Colhoun and Park, 1964), and the Rothamsted, Broom's Barn, and Woburn Experimental Stations (Snyder and Nash, 1968).

In Canada, Helminthosporium sativum is the primary cause of cereal root rot in the prairie provinces of Western Canada (Tinline, 1986; Verma, 1983; Sallans and Tinline, 1965; Ledingham, 1961; Broadfoot, 1934b) and in Prince Edward Island (Kimpinski and Johnston, 1985).

In other regions of the world, F. culmorum was reported to be the most prevalent root rot fungus in the Paris area of France (Cassini, 1967), southeast Hungary (Mesterhazy, 1974), southern Italy (Piglionica et al., 1975), and Poland (Manka et al., 1985). Fusarium graminearum predominates in Brazil (Diehl, 1979) and southwestern France (Cassini, 1967).

## Economic Importance

Root rot has had a detrimental effect on yield of cereals. Over the years 1939-1973, annual grain yield losses of 5-12.1% were reported for wheat in Canada (Ledingham et al., 1973; Sallans, 1960, 1953, 1948; Machacek, 1943). In

northwestern U.S.A., yield reduction was at least 10% in wheat fields infested with F. culmorum (Cook, 1968b). In Australia, Wearing and Burgess (1977) observed up to 20% deadheads and 100% plant infection by F. graminearum and Purss (1966) reported an average yield reduction of 26.6% for 10 wheat varieties grown in two locations in southeastern Queensland. In Canada, Piening et al. (1983) found a 16% yield loss for barley on fallow land, 30 and 40% on stubble, respectively, with and without fertilizer. Verma et al. (1976) reported grain yield loss of 26, 28 and 59% on wheat field plots showing, respectively, slight, moderate, and severe root rot infection caused by H. sativum. Correlations between yield and disease severity of -0.8 for F. culmorum and -0.6 for H. sativum were established for wheat by Greaney et al. (1938). Verma et al. (1976) found a significant relationship between disease severity on the subcrown internode and reductions in both dry weight and grain yield per plant.

Several yield components are affected by root rot pathogens. Reduction in emergence (Greaney et al., 1938), number of tillers (Machacek, 1943), number of heads per plant (Piening et al., 1976; Ledingham et al., 1973; Piening, 1973), number of kernels per ear (Sims et al., 1961; Machacek, 1943), kernel weight (Kidambi et al., 1985b;

Ledingham et al., 1973; Purss, 1966; Sims et al., 1961) and grain size (Sims et al., 1961) were reported.

## Inoculum Sources

### Seed as a source of inoculum

Low levels of seed infection by root rot pathogens have been reported from the warm and dry cereal-growing regions in the world. Chambers (1972) surveyed cereal seedlots produced in Victoria, Australia, and found F. culmorum in 1.2% of the seedlots, F. graminearum in 0.5% and F. avenaceum in 3.5%. Gordon (1944) reported 16 Fusarium species on cereal seed samples in Manitoba, Canada; with F. avenaceum present in 1.3% of the samples, F. culmorum in 0.3%, and F. graminearum in 0.9%. Average seed infection for these pathogens varied from 0.6 to 2.2%. In England, Hewett (1967) found F. culmorum in 0.3% of seed samples of wheat with a seed infection rarely over 3%. Lyamani (1975) tested 134 wheat seed samples from the main wheat-producing regions of Morocco and reported 10 Fusarium species, including F. avenaceum, F. culmorum, and F. graminearum. These three species were present, respectively, in 20.1, 5.2, and 5.2% samples with an average seed infection of 0.9, 1.8, and 1.0% respectively. Similar results were found in Finland (Uoti and Ylimaki,

1974; Ylimaki, 1970), and France (Cassini, 1970; Ponchet, 1960).

In areas where headblight is a serious problem, high levels of F. graminearum seed infection were observed. The pathogen was found in 65% seed samples of wheat produced in New York state (Crosier and Waters, 1959) and seed infection levels as high as 67% were observed in the Mid-Atlantic region of the U.S. (Halfon-Meiri et al., 1979), and 57% in France (Cassini, 1970).

Artificial seed inoculation with F. graminearum resulted in a much higher early infection of wheat plants and a significant increase in disease incidence and severity (Purss, 1966). Although no correlation could be clearly established between natural Fusarium seed infection and reduction in emergence or field dry yield (De Tempe, 1958), a highly significant correlation was found between natural seed infection and seed germination at 20 C, greenhouse emergence, and seedling infection (Halfon-Meiri et al., 1979). Misra et al. (1982) reported a correlation coefficient of -0.86 between Fusarium spp. wheat seed infection and germination values in the laboratory.

Soil as a source of inoculum

The primary structures of survival in soil for F. culmorum, F. graminearum, and H. sativum are chlamydospores, mycelium in crop refuse, and conidia, respectively (Verma et al., 1974; Cook, 1968b; Cook and Bruehl, 1968). Counts as high as 3000 and 5000 propagules of F. culmorum/g of soil, were found in France (Cassini, 1970) and the northwestern U.S.A., respectively (Papendick and Cook, 1974). Counts of 3125 propagules of F. graminearum/g of soil were observed in Australia (Wearing and Burgess, 1977). In Canada, counts of 407 conidia of H. sativum/g of soil were reported (Tinline, 1986; Duczek et al., 1985; Verma et al., 1974).

Infection from soil-borne inoculum of F. graminearum showed a progressive development from 38 days after planting until maturity (Purss, 1966). Wearing and Burgess (1977) found no correlation, under field conditions, between soil population of F. graminearum at the end of the growing season and disease severity or isolation frequencies. However, Cook (1968a) and Papendick and Cook (1974) observed an increase in disease incidence and severity associated with an increase in soil-borne inoculum of F. culmorum, and also reported a yield reduction.

Helminthosporium sativum soil-borne inoculum had a major role in both the initiation and the progression of cereal

root rot (Verma et al., 1976). In growth room and greenhouse experiments, Duczek et al. (1985) found that threshold levels inducing maximum root rot were 10-60 and 50-120 conidia/$cm^3$ for wheat and barley respectively.

## Infection Process and Survival

Malalasekera et al. (1973) and Atanasoff (1920) considered the coleoptile and the coleorhiza important sites for the penetration of F. culmorum and F. graminearum. Penetration of the coleoptile occurred through stomata and between the epidermal cells. Penetration of the coleorhiza occurred where the primary roots emerge (Malalasekera et al., 1973). The crown and subcrown tissue were also reported to be frequent sites of primary infection (Purss, 1969 and 1966; Cook, 1968b). Entry in the crown took place either where the secondary roots emerge or by infection of newly emerging crown roots (Cook, 1980). Isolation studies showed that the pathogens progress upward inside the stem as far as the internode below the head, and that in most instances infection is frequent in the basal 5-20 cm (Francis and Burgess, 1977; Mesterhazy, 1974; Cook and Bruehl, 1968; and Purss, 1966).

In infected wheat kernels, F. graminearum was frequently found at the embryo end and rarely in the testa, nucellar layer, and endosperm (Pugh et al., 1932). During the germination process, either the embryo is promptly killed and rotting follows, or the embryo germinates satisfactorily but the fungus penetrates and becomes established in the radicle and plumule (Russell, 1932).

Survival of root rot pathogens has been of great interest to many workers. Fusarium culmorum overwinters mainly as mycelial or conidial chlamydospores in soil (Sitton and Cook, 1981; Piglionica et al., 1975; Warren and Kommedahl, 1973; Cook, 1968b; Cook and Bruehl, 1968). Fusarium graminearum survives primarily as mycelium in plant debris (Wearing and Burgess, 1977), and although able to develop chlamydospores (Sitton and Cook, 1981; Nyvall, 1970), these structures are not extensively formed (Warren and Kommedahl, 1973) or are not formed at all (Wearing and Burgess, 1977). Fusarium avenaceum does not form chlamydospores (Warren and Kommedahl, 1973) and relies for its survival on overwintering mycelium or perithecia in plant debris (Snyder and Nash, 1968; Cook, 1967). Fusarium culmorum and F. graminearum are not good competitors against other soil fungi. They both colonize residues and host tissues mainly through parasitic activity (Wearing and

Burgess, 1977; Nyvall and Kommedahl, 1973; Warren and Kommedahl, 1973; Burgess and Griffin, 1968; Cook and Bruehl, 1968).

## Variation in Pathogenicity

There is worldwide agreement among workers that F. culmorum and F. graminearum are strong pathogens and F. avenaceum is a weak pathogen, while F. equiseti, F. sambucinum, F. scirpi, F. semitectum, F. moniliforme, F. sporotrichoides, F. fusaroides, F. tricinctum, F. flocciferum, F. oxysporum, F. solani, F. poae, F. acuminatum, and F. redolens are slightly pathogenic to non-pathogenic to the wheat plant (Mesterhazy, 1978; Uoti, 1976b; Piglionica et al., 1975; Colhoun et al., 1968; Colhoun and Park, 1964; Chambers, 1962; Oswald, 1949; Johnston and Greaney, 1942).

Considerable variability in virulence was commonly reported within pathogenic Fusarium species. It is common to see a range of pathogenicity within a single species similar to that observed between species. Johnston and Greaney (1942) tested 24 isolates of F. culmorum in the greenhouse and nine isolates in the field. Although there was no agreement between greenhouse and field results, a range of pathogenicity from none to extreme virulence was observed.

Sanford and Broadfoot (1934) tested 286 isolates of F. culmorum and found the great majority to be weak pathogens to nonpathogenic on seedling and adult wheat plants. A similar range of virulence was reported by other workers (Manka et al., 1985; Mesterhazy, 1978; Uoti, 1976a&b; Piglionica et al., 1975; Colhoun and Park, 1964; Oswald, 1949).

Virulence of F. graminearum isolates was studied by Manka et al. (1985), Mesterhazy (1978), Uoti (1976b), Purss (1969), Colhoun and Park (1964), and Oswald (1949). All isolates tested were pathogenic to wheat although considerable differences in pathogenicity were observed.

Helminthosporium sativum isolates were tested by Kidambi et al. (1985a) and Sanford and Broadfoot (1934), on barley and wheat respectively. All isolates tested were moderate to weak pathogens with no differences between isolates in the barley test. When compared to F. roseum sensu Snyder & Hansen, H. sativum was less virulent to wheat (Statler and Darlington, 1972).

Pathogenic specialization within Fusarium species causing root rot was reported by Oswald (1949), who found some isolates to be pathogenic to some gramineous hosts but non-pathogenic to others, and also by Purss (1971), who noticed that F. graminearum cultures from maize were pathogenic to maize but non-pathogenic to wheat. There was

no such evidence of pathogenic specialization in F. roseum (L. K.) Snyd. and Hans. (Tammen, 1958) or F. culmorum (Piglionica et al., 1975; Russell, 1932).

Virulence of root rot pathogens was enhanced by increasing inoculum density and soil temperature, and decreasing soil moisture (Kidambi et al, 1985a; Cook et al., 1972; Colhoun et al., 1968; Johnston and Greaney, 1942; Shen, 1940; Dickson, 1923).

## Epidemiological Factors

### Agronomic

Seeding rate (or plant density) affects plant competition for water and nutrients present in the soil and thus may affect root rot development. While Tinline (1986) and Broadfoot (1934a) found no effect of seeding rate on common root rot chiefly caused by H. sativum, Papendick and Cook (1974) and Greaney (1946) reported that increasing seeding rate resulted in an increase in root rot incidence and a decrease in yield.

Time of seeding has a relationship with soil temperature at planting. High soil temperature favors root rot development (Halfon-Meiri et al., 1979; Stover, 1953; Greaney, 1946; Dickson, 1923). Seeding winter wheat at the

latest safe date in fall and spring wheat at the earliest safe date in spring resulted in less seedling blight, root rot of adult plants, and yield reduction (Greaney, 1946; Robertson et al., 1942; Broadfoot, 1934a; Dickson, 1923).

The effect of depth of seeding is controversial. Tinline (1986) and Greaney (1946) reported an increase in wheat root rot incidence and severity with increasing depth. However, Colhoun et al. (1968) saw no such influence.

The plowing method, such as moldboard, sweep, or disk, had no effect on Fusarium root rot of wheat in Oregon (Hall, 1959).

Soil fertilization affects available nutrients in the soil and therefore development of plants and soil microflora including the plant pathogens. Application of nitrogen fertilizer intensified root rot severity in cereals (Garrett, 1976; Papendick and Cook, 1974; Ledingham, 1970; Kaufmann and Williams, 1964). An opposite effect was found by others (Afanas'eva and Chulkina, 1977; Sims et al., 1961). Effects of phosphate fertilizer application on root rot varied. While Verma et al. (1975) and Sims et al. (1961) reported a root rot reduction, Greaney (1938) reported no effect and Russell and Sallans (1940) reported enhanced disease intensity.

Crop rotation influenced the diversity and quantity of the soil-borne mycoflora including root rot pathogens (Williams and Schmithenner, 1962). Root rot developed to the greatest degree where wheat followed wheat, corn, oats, or barley (Cook, 1968a; Cassini, 1967; Kommedahl and Young, 1956; Broadfoot, 1934a) and developed least when wheat followed summer fallow, oats, or barley (Kommedahl and Brock, 1954; Oswald, 1950; Sanford, 1946; Broadfoot, 1934a). Contradictory results for barley and oats may be accounted for by differences in varietal resistance. Compared to continuous wheat, one or two years of summer fallow or oats did not reduce Fusarium-Helminthosporium root rot incidence. Long rotations of 3 years or more are needed to control the disease (Ledingham, 1961).

Seed vigor is used in the present study as defined by the Association of Official Seed Analysts (AOSA) (1983): "Seed vigor comprises those properties which determine the potential for rapid, uniform emergence and development of natural seedlings under a wide range of field conditions". Effects of seed vigor on root rot of wheat was investigated by few workers. Machacek and Greaney (1936, 1933) planted mechanically injured wheat seed showing a low vigor in soils inoculated with F. culmorum and found significantly higher root rot incidence in treatment with mechanically injured

seed than in those with uninjured seed. Mesterhazy (1983) noticed that seedlings from two year old seed were much more susceptible to Fusarium root rot than were seedlings from freshly harvested seed.

Climatic

The effects of soil moisture and temperature on root rot development have been recognized since the investigation carried out by Dickson in 1923. In Australia and in the Pacific Northwest U.S., severe root and foot rot of wheat were associated with below-average rainfall during the growing season (Cook, 1968b; McKnight and Hart, 1966). Lack of moisture during early plant growth stages was reported to be especially important for the prevalence of crown rot (McKnight and Hart, 1966). However, Kidambi et al. (1985a) and Purss (1966) found no relationship between moisture stress and disease development.

Seedling blight and foot rot were also reported to be favored by higher temperatures and drier soils (Halfon-Meiri et al., 1979; Stover, 1953; Dickson, 1923). Greaney (1946) reported a significant positive correlation between high soil temperature at planting, and seedling and adult root rot ratings, and a highly significant negative correlation between soil temperature at planting and yield.

## Control

### Host resistance

*Fusarium culmorum* showed equal virulence on wheat, barley, and oats but *H. sativum* was less injurious to wheat than barley and hardly pathogenic to oats (Russell, 1932). Durum wheat was more susceptible to *Fusarium* root rot than bread wheat (Cassini, 1967).

There was no pronounced degree of resistance to *Helminthosporium* - *Fusarium* root rot in any of the wheat varieties tested (Sims et al., 1961; Greaney et al., 1938; Russell, 1932). However, significant differences among varieties were observed (Statler and Darlington, 1972; Greaney et al., 1938), with those resistant to *F. culmorum* also resistant to *H. sativum*, and those susceptible to *F. culmorum* also susceptible to *H. sativum* (Greaney et al., 1938). McNight and Hart (1966) saw differences in reaction among 18 varieties of wheat at both seedling and maturity stages to *F. graminearum* root rot. Kommedahl and Patel (1966) tested 412 local varieties and lines and 337 from other states and countries for their resistance to common root rot caused primarily by *F. roseum*. They found that most local varieties were resistant to slightly susceptible while most out-of-state varieties were moderately resistant.

Piglionica et al. (1975) inoculated seedlings of four durum wheat varieties and reported pronounced differences among varieties in their reaction to F. culmorum and small to no differences in their reaction to F. graminearum and F. avenaceum.

The relationship between plant growth stage and host resistance was investigated by McNight and Hart (1966), Greaney (1946), and Broadfoot (1934b). The seedling stage appeared to be more susceptible than later stages.

Chemical

Chemical control has been successfully used to eradicate seed-borne inoculum of cereal root rot fungi. Soil-borne inoculum, however, has been difficult to control by seed treatment because root infection may occur at later growth stages when the fungicide has been diluted (Hampton, 1978; Das and Srivastava, 1971; Mikhalina, 1970; Wallace and Mills, 1968; McNight and Hart, 1966; De Tempe, 1958). Seed treatment with systemic fungicides provided a better protection over longer periods against root infection. Thiabendazole (Cassini, 1970, 1967) and Benomyl + Thiram (Diehl and Reis, 1983; Martin and Johnston, 1982) were the most effective fungicides against Fusarium seed infection. Similarly, H. sativum seed infection was effectively

controlled by Nuarimol (Diehl et al., 1983; Verma, 1983; Reis, 1982) and Fenapronil (Diehl et al., 1983) fungicides. Although the chemicals allowed good disease control, the yield either was not affected or sometimes was reduced (Piening et al., 1983; Verma, 1983; McNight and Hart, 1966). Chinn and Ledingham (1962) found that Vapam and Chloropicrin both at 16.6 ppm were effective in eradicating F. culmorum and H. sativum from infected soils.

Biological

Biological control has been considered and used to control root rots of cereals. Sanford and Broadfoot (1931) and Henry (1931) demonstrated the depressive effect of the natural microflora of soil on cereal rotting fungi. Trichoderma lignorum has been an excellent antagonist to both F. culmorum and H. sativum (Uoti, 1976b; Johnston and Greaney, 1942; Bisby et al., 1933). Pyrenema confluens, Chaetomium cochlioides, Chaetomium globosum, and Penicillium spp. showed some degree of biological control of root rot pathogens (Uoti, 1976b; Johnston and Greaney, 1942). Piglionica et al. (1975) reported that nonpathogenic isolates of Fusarium having conidia morphologically similar to those of F. culmorum protected wheat plants up to maturity from a virulent isolate of F. culmorum.

# MATERIALS AND METHODS

## Survey of Root Rot and Associated Pathogens in Wheat Fields in West Central Morocco

### Sampling procedure

In the 1985/86 and 1986/87 cropping seasons, surveys of wheat fields were conducted during the month of April at Feekes' growth stages (FGS) 10.5.3 to 11.1 which corresponded to late flowering - early ripening of the crop (Large, 1954). Single fields were randomly selected 10K apart in the province of Settat covering approximately 1,175,000 ha south of Casablanca, Morocco (Figure 1). Each field was entered at a corner and at a distance of 25 paces along the diagonal line approximately 10 plants were sampled. Care was taken to minimize breakage of the roots and the plants were stored in a cloth bag. From the same site, one soil core was taken with a 65 mm diameter soil probe to a depth of 20 cm and stored in a cloth bag. This procedure was repeated at four more sites at equal distance along the diagonal. All 5 samples of plants and soil cores were pooled to give one sample of each per field.

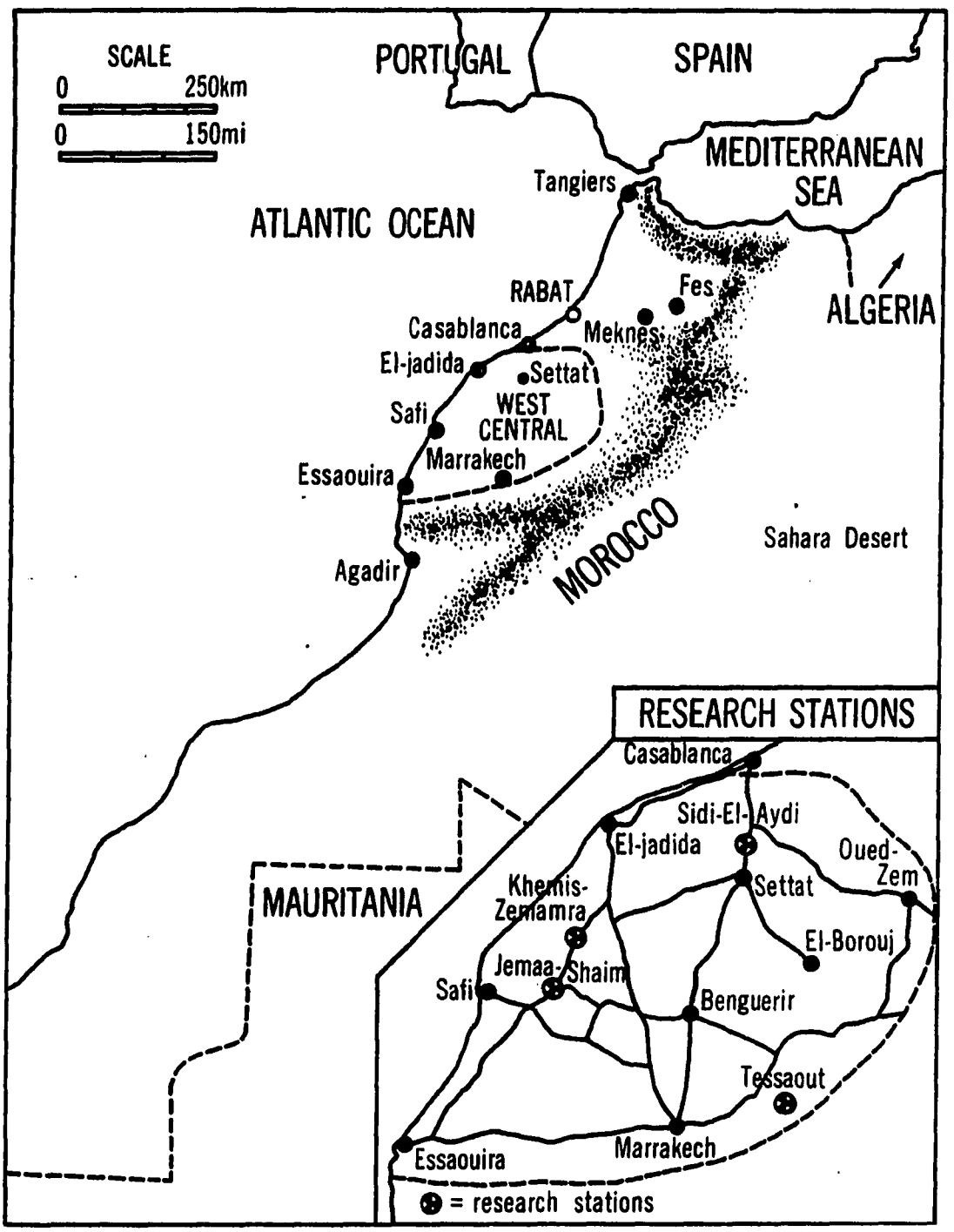


Figure 1. Map of Morocco indicating the west central region and research stations where field experiments were located

Root rot ratings

Plant roots were soaked for 2 hours in 10 liters of tap water, containing 10 ml of liquid detergent, then rinsed in a high pressure stream of tap water. Roots were rated for disease using a numerical rating assigned to each plant (Greaney et al., 1938; Table 1), and a root rot severity index calculated for each field using the formula:

$$\text{RRSI} = \frac{\text{Sum of numerical ratings of individual plants} \times 100}{\text{Number of plants examined} \times 5}$$

The disease severity is therefore expressed on a 0-100 scale where 0= all plants are root rot free and 100= all plants are killed.

Prevalence of Fusarium spp. in wheat fields

Isolations from roots A 5-mm root segment was cut from each plant with a numerical root rot rating >0. For each sample, segments from plants showing the same numerical rating were pooled, then surface sterilized for 1 min in a solution containing 1.3% sodium hypochlorite, washed twice in distilled sterile water, allowed to damp-dry on sterile blotter paper, and plated on potato-dextrose agar (PDA). Plates were then incubated for 5-7 days at room temperature. The fungi growing from root pieces were identified and enumerated. Representative cultures of each Fusarium species found were subcultured onto PDA, incubated for 7 days, then

Table 1. Numerical ratings used to record the severity of root rot on individual wheat plants

| Numerical rating | Root rot symptoms on individual plants |
|---|---|
| 0 | No root rot. |
| 1 | Small, scattered necrotic lesions on subcrown internode, or roots. |
| 2 | Distinct, dark lesions on basal parts, particularly on subcrown internode and roots. |
| 3 | Large, necrotic lesions on crown, subcrown internode, and roots, with loss of plant vigor. |
| 4 | Severe rotting of basal parts, plant chlorotic, often wilted or stunted; some culms dead. |
| 5 | Plant killed before maturity. |

stored at 4 C until used.

Isolations from soils Soil samples were air-dried at room temperature (20-25 C), then passed through a 2 mm sieve. A 10 g subsample was placed in 90 ml of sterile water and shaken for 30 min. The suspension was diluted further in sterile water to 1/100 and 1/500. From each dilution, 1 ml aliquots were pipetted onto modified Nash-Snyder Fusarium selective medium (Nelson et al., 1983) in three petri dishes. The inoculated plates were incubated at room temperature (20-25 C) and daylight for 3-5 days. Fusarium colonies were counted at the 1/100 dilution, when possible, otherwise the count was from 1/500 dilution plates. Representative subcultures of each Fusarium sp. were transferred onto PDA plates and stored at 4 C until used.

Identification of Fusarium species Each stored Fusarium isolate was cultured on fresh PDA. A 5 mm disk was cut from the growing edge of the colony and transferred into a 60 mm diameter petri dish containing water agar and sterilized pieces of carnation leaf (Nelson et al., 1983). Cultures were incubated for 2-3 weeks at room temperature (20-25 C) in daylight, and isolates identified to the species level according to Nelson et al. (1983).

The identities of representative isolates of Fusarium species encountered in this study were later verified by

P. E. Nelson. Isolates of F. compactum, F. culmorum, and F. graminearum were included in the culture collection at the Fusarium Research Center, 211 Buckout Laboratory, Department of Plant Pathology, Pennsylvania State University, University Park, PA.

Isolation of Fusarium species from wheat seed Seed samples were collected during planting time, mid-November to late December, 1986 and 1987 in the region described earlier. These were obtained from locations 10K apart by requesting a seed sample from farmers in the process of seeding their fields and were stored at 4 C in cloth bags.

Fusarium seed infection was determined using the deep-freeze method of Limonard (1968). Two hundred seeds were tested for each sample by placing 25 seeds in a 100 mm diameter petri dish on three layers of moistened Whatman No. 2 blotter paper. The dishes were incubated for 3 days at 20 C in the dark, transferred to a freezer at -20 C for 16 hours, then incubated 5 days at room temperature (20-25 C) under an alternating cycle of 16 hours light and 8 hours darkness (Limonard, 1968; Leach, 1967). Fungi growing on seeds were identified under a stereomicroscope. Fusarium species were isolated to PDA and identified to the species level on carnation leaf agar as described.

## Field Experiments

### Locations

Soil type, crop history, and climatic conditions at experimental sites used in the 1985/86 and 1986/87 growing seasons are described in Figure 1 and Tables 2-4. Rainfall allowed ample moisture throughout the 1985/86 season but in 1986/87 rainfall was not sufficient and drought stress prevailed. Field experiments were conducted under the dryland cropping conditions of the region.

### Soil inoculation

One isolate of F. culmorum and one isolate of H. sativum were obtained in October 1985 from a wheat field at Sidi El Aydi Experiment Station and used throughout this study. Inoculum of each of the two isolates was produced on a mixture of equal parts of sterilized wheat and oat seed. This substrate was prepared by placing 25 g of the seed mixture in 50 ml distilled water and autoclaving for 30 min. at 134 C twice during two successive days. Cultures were incubated for three weeks. Soils were manually inoculated immediately before planting by placing inoculum into the planting rows at a rate of 10 g/1-m row.

Table 2. Description of fields used in 1985-86 and 1986/87 experiments

| Location | Growing season | Fertilizer | Soil types |
|---|---|---|---|
| Sidi El Aydi | 85/86<br>86/87 | 80/80/60[a]<br>80/80/60 | Vertic-calcixeroll |
| Khemis Zemamra | 86/87 | 80/80/60 | Vertisol |
| Jemaa Shaim | 86/87 | 20/40/0 | Vertisol |
| Tessaout | 86/87 | 80/80/60 | Alfisol |

[a]Kg/ha of N/P/K.

Table 3. Mean temperature (degrees Celsius) recorded in 1985/86 and 1986/87 cropping seasons at four locations in West Central Morocco

| | Location and growing season | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sidi El Aydi | | Khemis Zemamra | Jemaa Shaim | | Tessaout | |
| Month | 85/86 | 86/87 | 86/87 | 85/86 | 86/87 | 85/86 | 86/87 |
| September | 24.2 | 21.8 | 24.6 | 23.1 | 22.3 | 23.2 | 24.4 |
| October | 20.3 | 19.5 | 20.0 | 20.3 | 19.7 | 20.3 | 18.5 |
| November | 16.4 | 15.7 | 15.5 | 17.6 | 15.0 | 13.5 | 14.7 |
| December | 13.1 | 12.0 | 12.7 | 12.7 | 12.0 | 9.7 | 10.8 |
| January | 12.5 | 13.8 | 13.4 | 10.7 | 13.0 | 10.0 | 12.6 |
| February | 13.8 | 13.4 | 13.4 | 12.2 | 14.2 | 11.2 | 12.1 |
| March | 14.5 | 15.5 | 16.2 | 12.9 | 18.4 | 12.8 | 15.7 |
| April | 15.7 | 18.9 | 18.8 | 12.9 | 19.8 | 14.6 | 19.8 |
| May | 20.2 | 17.8 | 19.4 | 19.7 | 22.8 | 21.7 | 19.2 |

Table 4. Rainfall (mm) recorded in the 1985/86 and 1986/87 cropping seasons at four locations in West Central Morocco

| | Location and growing season | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sidi El Aydi | | Khemis Zemamra | | Jemaa Shaim | | Tessaout | |
| Month | 85/86 | 86/87 | 85/86 | 86/87 | 85/86 | 86/87 | 85/86 | 86/87 |
| September | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| October | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 34.0 |
| November | 52.6 | 38.5 | 35.4 | 28.1 | 44.8 | 32.5 | 21.4 | 34.6 |
| December | 31.1 | 5.0 | 42.7 | 6.0 | 46.0 | 9.7 | 34.7 | 0.2 |
| January | 46.7 | 45.0 | 27.7 | 52.7 | 33.5 | 51.0 | 23.3 | 34.0+ 50.0[a] |
| February | 79.1 | 57.0 | 77.6 | 51.3 | 77.9 | 63.6 | 37.2 | 63.1 |
| March | 21.5 | 38.1 | 47.0 | 45.3 | 35.5 | 10.5 | 31.9 | 13.5+ 50.0[a] |
| April | 48.4 | 12.8 | 42.7 | 8.0 | 33.0 | 16.5 | 8.0 | 0.7 |
| May | 0.0 | 7.0 | 0.0 | 5.6 | 0.0 | 15.0 | 28.4 | 0.0 |
| TOTAL | 279.4 | 203.4 | 273.1 | 197.0 | 270.7 | 198.8 | 186.1 | 180.1+ 100.0[a] |

[a]Supplied through gravity irrigation.

Seed inoculation

*Fusarium culmorum* and *H. sativum* isolates used in soil inoculation were also grown on PDA for 15 days at room temperature as previously described. Mycelia and spores were scraped off the plates, and washed with distilled sterile water. The washings were then strained through one layer of sterilized cheesecloth, and spore suspensions were adjusted by adding sterile water to the concentrations of $1.8 \times 10^6$ and $1.0 \times 10^5$ spores/ml in 1985/86 and 1986/87 respectively. Seeds were inoculated by placing 100 ml of the fungal spore suspension in a plastic bag containing 1 kg of seed. This was mixed for 5 min., dried overnight at room temperature (20-25 C) and then planted.

Row spacing

Row spacings of 20, 40, or 60 cm were used to obtain high, medium and low planting density. The seeding rate in each was constant at 40 viable seeds per 1-m row. Seed viability was determined using a standard germination test (ISTA, 1976).

Yield data

Plots were harvested in the first week of June in each season with a binder and a stationary thresher. Total yield

was obtained by weighing straw + grain together. Grain yield was measured after the threshing and cleaning process. Straw yield was obtained by substracting grain from total yield.

Experiment 1: Effect of seed and soil-borne inoculum of Fusarium culmorum on root rot development and agronomic performance of wheat

This experiment was carried out at Sidi El Aydi in 1985/86 and 1986/87 cropping seasons using the durum wheat variety Cocorit. Plot size was 5 rows, 4-m long. Groups of plots were inoculated with F. culmorum by seed inoculation, soil inoculation, seed and soil inoculation, or no inoculation. For seed inoculation, spore suspensions of 1.8 X $10^6$ and 1.0 X $10^5$ spores/ml were used in the 1985/86 and 1986/87 seasons, respectively. Three row spacings were used for each inoculation treatment. Inoculation X row spacing treatments were arranged in a factorial randomized complete block design with four replications. Seedling emergence counts were taken at Feekes' growth stage 1-3 on the whole 4-m length of the two rows adjacent to the central one and results expressed in number of plants per square meter. Measurements of root rot severity were made at Feekes' growth stages 8-9 and 10.5.3 (respectively mid-stem extension and end of flowering). Plant samples were taken

from the three center rows. Roots were washed free from soil and 10 plants/plot were scored for disease.

Deadhead rating was taken on a 3-meter length of the two rows adjacent to central one. A deadhead is a prematurely ripened tiller with a bleached ear appearing white in a field otherwise green. Total and grain yield data were obtained, as described above, from three center rows on a 3-meter lengths.

Experiment 2: Effect of seed vigor on root rot development

Four seedlots of the durum wheat Cocorit were planted at Sidi El Aydi during the 1985/86 and 1986/87 seasons on land left fallow the preceding year. All the plots were inoculated by incorporating into soil a virulent isolate of F. culmorum as described above. The seedlots were not inoculated.

Seed vigor was determined by the seedling growth rate procedure (Association of Official Seed Analysts, 1983). Four replicates of 50 seeds from each seedlot were placed on three moistened 34 X 58 cm Whatman No. 2 blotter towels, and placed in a germinator at 20 C for 7 days. Germination counts were made and the weight of normal seedlings was determined after drying at 80 C for 24 hr. Four seedlots showing a range of vigor levels (Table 5) and three row spacings (20, 40 and 60 cm); were arranged in a split-plot

Table 5. Description of seedlots used in the field experiment 2 to investigate the effects of seed vigor on root rot development

| Season | Seedlot order number | Seedlot vigor (seedling weight in mg) |
|---|---|---|
| 1985/86 | 1 | 22.4[a] |
| | 2 | 20.0 |
| | 3 | 19.7 |
| | 4 | 17.4 |
| 1986/87 | 1 | 17.6 |
| | 2 | 15.9 |
| | 3 | 10.6 |
| | 4 | 9.9 |

[a]Four replicates of 50 seeds, determined by the seedling growth rate test (Association of Official Seed Analysts, 1983).

experimental design with row spacing as the main plots and seedlots as sub-plots. Each treatment was replicated four times. Plots consisted of 5 rows, 4-m long. Measurements of seedling emergence, root rot and deadhead ratings, straw and grain yields were recorded as described above.

Experiment 3: Effect of F. culmorum and H. sativum on root rot, plant emergence and crop yield of four wheat varieties

Durum wheat varieties Cocorit, Marzak, Karim, and Kyperounda were planted at Sidi El Aydi Experiment Station during 1985/86 and 1986/87 growing seasons. Individual plots consisted of 4 rows, 2.4-m long. Plots were inoculated as follows: 1) seed and soil inoculated with F. culmorum, 2) seed and soil inoculated with H. sativum, and 3) seed and soil uninoculated. Each combination of variety and inoculation method was planted at the three row spacing described above. The experiment was planted in a split-split-plot design with the variety being the main plot, row spacing the sub-plot, and inoculation treatment the sub-sub-plot. Measurements of seedling emergence, deadhead, straw and grain yields were taken on the two central rows as described. Root rot severity was determined as described on one sample of 10 plants per plot taken from two the central rows on March 17, April 15, and May 8, 1987; at Feekes'

growth stage 8-9, 10.5.3 and 11.1 respectively.

Experiment 4: Effect of Fusarium culmorum natural and artificial seed-borne inoculum on root rot, plant emergence and crop yield of four wheat varieties

Twelve seedlots with a 0-8% range of F. culmorum natural seed infection were identified in the survey described above (Table 6). These lots, and one seedlot of each of the varieties Cocorit, Marzak, Karim, and Kyperounda, inoculated with F. culmorum; were planted at Sidi El Aydi, Khemis Zemamra, Jemaa Shaim, and Tessaout (Figure 1; Tables 2, 3 and 4). These locations were chosen to represent different climatic conditions and natural levels of soil-borne inoculum of F. culmorum. To evaluate the effects of seed treatment on seed- and soil-borne inoculum, each seedlot was planted either untreated or treated with Thiabendazole at 100 g a.i./100 kg seed. At each location, the 16 seedlots and two seed treatments were arranged in a factorial complete block design with three replications. Plots consisted of six rows, 6-m long, and 30 cm apart. Seeding rate was 40 viable seeds per meter row length. Seedling emergence counts were taken at FGS 1-3 on a 2-m length of each of four center rows. Measurement of disease ratings was made at FGS 8-9 on one 50-plant sample taken from the four central rows of each plot.

Deadhead ratings were made at FGS 11.1 at Sidi El Aydi and Tessaout. This was not possible at Khemis Zemamra and Jemaa Shaim because of a severe drought stress. Straw and grain yields were obtained at all locations by harvesting four central rows on 4-m length.

Table 6. Description of seedlots used in the 1986/87 experiment 4

| Seedlot order Number | Variety | Type of infection | Seed treatment[a] NT | T |
|---|---|---|---|---|
| 1 | Cocorit | Natural | 8[b] | 0 |
| 2 | Cocorit | Natural | 4 | 0 |
| 3 | Cocorit | Natural | 4 | 0 |
| 4 | Cocorit | Natural | 1 | 0 |
| 5 | Cocorit | Natural | 1 | 0 |
| 6 | Cocorit | Natural | 0 | 0 |
| 7 | Marzak | Natural | 6 | 0 |
| 8 | Marzak | Natural | 3 | 0 |
| 9 | Karim | Natural | 4 | 0 |
| 10 | Karim | Natural | 3 | 0 |
| 11 | Kyperounda | Natural | 2 | 0 |
| 12 | Kyperounda | Natural | 0 | 0 |
| 13 | Cocorit | Inoculation[c] | 80 | 0 |
| 14 | Marzak | Inoculation | 96 | 0 |
| 15 | Karim | Inoculation | 100 | 0 |
| 16 | Kyperounda | Inoculation | 99 | 0 |

[a]Seeds were either non treated (NT) or Treated (T) with the fungicide Thiabendazole at a rate of100 g a.i./100 kg seed.

[b]% seed in which F. culmorum was detected. This was determined on 200 seeds tested with deep freeze method.

[c]Seed inoculated by a F. culmorum virulent isolate at the rate of 100 ml of a $10^5$ spores/ml suspension per 1 kg seed.

# RESULTS

## Survey of Root Rot and Associated Pathogens in Wheat Fields in West Central Morocco

### Root rot incidence and severity

Approximately 79.2 and 53.7% of the fields surveyed in 1985/86 and 1986/87 cropping seasons respectively had root rot indices smaller or equal to 10 (Table 7). The highest found in 1985/86 was 20 and in 1986/87 it was 25. Of all plants in the survey, 27.0% showed detectable symptoms (rot ratings>0) in 1985/86, and 39.9% in 1986/87 (Table 8). In both seasons most diseased plants were in severity category 1. Categories 2, 3, and 4 were occasionally encountered and 5 was not observed. In general, root rot severity and incidence was greater in the drier 1986/87 season than in 1985/86.

### Fungi associated with root rot

Eight *Fusarium*, one *Helminthosporium* and one *Stemphylium* species were isolated from roots showing rot symptoms (Table 9). In both seasons, *H. sativum* and *F. equiseti* were isolated most frequently from fields, *F. oxysporum*,

Table 7. Root rot severity index and % affected wheat fields at Feekes' growth stages 10.5.3-11.1 in WestCentral Morocco in 1985/86 and 1986/87cropping seasons

| Class of root rot severity index[a] | % Affected Fields | |
|---|---|---|
| | 1985/86 | 1986/87 |
| 0 | 1.3 | 0.0 |
| 1 - 5 | 44.1 | 20.4 |
| 6 - 10 | 33.8 | 33.3 |
| 11 - 15 | 13.0 | 22.2 |
| 16 - 20 | 7.8 | 18.5 |
| 21 - 25 | 0.0 | 5.6 |
| Number of fields | 77 | 54 |

[a]Determined on one 50-plant sample/field by rating each plant on a 0-5 numerical scale where 0= no infection, 1= small, scattered necrotic lesions on subcrown internode or root and 5= plant killed before maturity. Root rot severity index (RRSI) was then calculatedusing the formula:

$$RRSI = \frac{\text{Sum of individual plant numerical ratings X 100}}{\text{Total number of plants X 5}}$$

Table 8. Number of plants associated with each root rot numerical rating in wheat fields surveyed in West Central Morocco in 1985/86 and 1986/87 seasons

| Numerical root rot rating | 1985/86 Number of plants | % | 1986/87 Number of plants | % | Total Number of plants | % |
|---|---|---|---|---|---|---|
| 0[a] | 2810 | 73.0 | 1617 | 59.9 | 4427 | 67.6 |
| 1 | 732 | 19.0 | 810 | 30.0 | 1542 | 23.5 |
| 2 | 270 | 7.0 | 189 | 7.0 | 459 | 7.0 |
| 3 | 23 | 0.6 | 70 | 2.6 | 93 | 1.4 |
| 4 | 15 | 0.4 | 14 | 0.5 | 29 | 0.4 |
| 5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Total | 3850 | 100.0 | 2700 | 100.0 | 6550 | 100.0 |

[a]Root Rot Rating of individual plants expressed on a 0-5 scale where 0= no infection , 1= small, necrotic lesions on subcrown internode or roots and 5= plant killed.

Table 9. *Fusarium* species and other fungi associated with root rot in wheat fields surveyed during 1985/86 and 1986/87 seasons in West Central Morocco

| | The fungus was detected in | | | |
|---|---|---|---|---|
| | % Fields[a] | | % Plants[b] | |
| Fungi[c] | 1985/86 | 1986/87 | 1985/86 | 1986/87 |
| *F. acuminatum* | 10.4 | 0.0 | 3.5 | 0.0 |
| *F. avenaceum* | 7.8 | 5.5 | 2.7 | 8.7 |
| *F. culmorum* | 24.7 | 24.1 | 15.3 | 13.1 |
| *F. equiseti* | 40.3 | 53.7 | 11.6 | 11.7 |
| *F. graminearum* | 5.2 | 7.4 | 21.5 | 23.5 |
| *F. moniliforme* | 0.0 | 3.7 | 0.0 | 15.0 |
| *F. oxysporum* | 2.6 | 33.3 | 7.0 | 8.9 |
| *F. solani* | 19.5 | 5.5 | 10.8 | 4.7 |
| *Helminthosporium sativum* | 81.8 | 94.4 | 11.8 | 14.2 |
| *Stemphylium* sp. | 7.8 | 0.0 | 5.3 | 0.0 |

[a]Number of fields surveyed were 77 in 1985/86 and 54 in 1986/87.

[b]Mean within infected fields only.

[c]A 5-mm root segment was cut from each plant with numerical root rot rating >0, plated on PDA and fungi present counted and identified.

F. solani and F. culmorum were less frequent, and F. avenaceum, F. acuminatum, F. graminearum and Stemphylium sp. were the least found.

Fusarium culmorum was most often detected on plants with root rot ratings of 3 and 4 (Tables 10 and 11), whereas, H. sativum was more evenly distributed across ratings of 1 to 4. The remaining fungi were more generally associated with root disease ratings of 1 and 2.

Fusarium species occurring in soil

Eleven Fusarium species were isolated from soils (Table 12). In both 1985/86 and 1986/87, F. equiseti was detected in almost every field, F. solani was detected in about half the fields, F. oxysporum in about 1/3, and the other Fusarium species occurred infrequently. Average numbers of propagules for the individual fungi in fields in which they were recovered ranged from 200 to 4200 per g of soil.

Fusarium spp. and Helminthosporium sativum occurring on seed

In 1985/86, H. sativum, F. culmorum, F. equiseti, and F. moniliforme species were isolated from wheat seedlots produced in West Central Morocco (Table 13). In 1986/87, F. graminearum , F. oxysporum, F. solani and F. poae were also isolated from wheat seedlots and F. equiseti was found on

Table 10. Frequency of isolation of Fusarium species and other fungi associated with each root rot rating in 1985/86 growing season in West Central Morocco

| Fungi[b] | Numerical root rot ratings[a] | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| | % | | | | |
| F. acuminatum | 0.9[c] | 1.5 | 0.0 | 6.3 | 0.0 |
| F. avenaceum | 1.8 | 1.1 | 0.0 | 0.0 | 0.0 |
| F. culmorum | 13.1 | 11.8 | 32.0 | 50.0 | 0.0 |
| F. equiseti | 19.0 | 17.3 | 12.0 | 6.3 | 0.0 |
| F. graminearum | 4.0 | 3.7 | 12.0 | 0.0 | 0.0 |
| F. moniliforme | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| F. oxysporum | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| F. solani | 7.3 | 7.0 | 4.0 | 0.0 | 0.0 |
| Helminthosporium sativum | 31.3 | 46.9 | 36.0 | 31.3 | 0.0 |
| Stemphylium sp. | 1.9 | 0.7 | 0.0 | 0.0 | 0.0 |
| Unidentified | 19.8 | 10.0 | 4.0 | 6.1 | 0.0 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

[a]Determined by rating each plant on a 0-5 numerical scale where 0= no infection, 1= small, scattered necrotic lesions on subcrown internode or root and 5= plant killed.

[b]A 5-mm root segment was cut from each plant with numerical root rot rating >0, plated on PDA and growing fungi identified.

[c]% based on total number of 732, 270, 23, 15, and 0 plants respectively showing the numerical ratings of 1 to 5.

Table 11. Frequency of isolation of *Fusarium* species and other fungi associated with each numerical root rot rating during 1986/87 growing season in West Central Morocco

| Fungi[b] | Numerical root rot ratings[a] | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| | % | | | | |
| *F. acuminatum* | 0.0[c] | 0.0 | 0.0 | 0.0 | 0.0 |
| *F. avenaceum* | 1.4 | 1.1 | 0.0 | 0.0 | 0.0 |
| *F. culmorum* | 6.3 | 6.9 | 21.1 | 42.9 | 0.0 |
| *F. equiseti* | 14.7 | 19.0 | 11.3 | 21.4 | 0.0 |
| *F. graminearum* | 4.2 | 4.2 | 5.6 | 7.1 | 0.0 |
| *F. moniliforme* | 0.0 | 1.7 | 0.5 | 0.0 | 0.0 |
| *F. oxysporum* | 7.7 | 6.3 | 1.4 | 7.1 | 0.0 |
| *F. solani* | 0.4 | 3.7 | 1.4 | 0.0 | 0.0 |
| *Helminthosporium sativum* | 30.1 | 45.0 | 45.1 | 21.4 | 0.0 |
| *Stemphylium* sp. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Unidentified | 33.5 | 13.3 | 14.1 | 7.3 | 0.0 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

[a]Determined by rating each plant on a 0-5 numerical scale where 0= no infection, 1= small, scattered necrotic lesions on subcrown internode or root and 5= plant killed.

[b]A 5-mm root segment was cut from each plant with numerical root rot rating >0, plated on PDA and growing fungi identified.

[c]% based on total numbers of 810, 189, 70, 14, and 0 plants respectively showing the numerical ratings of 1 to 5.

Table 12. *Fusarium* species occurring in soils of wheat fields in West Central Morocco during 1985/86 and 1986/87 seasons

| *Fusarium* spp. | The fungus was detected | | | |
|---|---|---|---|---|
| | In % fields[a] | | Propagules/g soil[b] | |
| | 1985/86 | 1986/87 | 1985/86 | 1986/87 |
| *F. acuminatum* | 1.6 | 0.0 | 3000 | 0 |
| *F. avenaceum* | 1.6 | 2.1 | 200 | 500 |
| *F. compactum* | 1.6 | 0.0 | 4200 | 0 |
| *F. culmorum* | 6.3 | 4.2 | 1000 | 500 |
| *F. equiseti* | 90.5 | 95.8 | 2600 | 1500 |
| *F. graminearum* | 0.0 | 2.1 | 0 | 1000 |
| *F. moniliforme* | 0.0 | 4.2 | 0 | 1000 |
| *F. oxysporum* | 28.6 | 47.9 | 3050 | 1700 |
| *F. poae* | 0.0 | 8.4 | 0 | 200 |
| *F. sambucinum* | 3.2 | 2.1 | 2500 | 600 |
| *F. solani* | 54.0 | 50.0 | 2400 | 1800 |

[a]Based on 63 fields in 1985/86 and 48 in 1986/87 season.

[b]Mean includes infected fields only.

Table 13. Occurrence of *Fusarium* and *Helminthosporium* species on wheat seed produced in the West Central Morocco in 1985/86 and 1986/87 seasons

| Fungi | The fungus was detected in | | | |
|---|---|---|---|---|
| | % samples[a] | | % seed[b] | |
| | 1985/86 | 1986/87 | 1985/86 | 1986/87 |
| *F. culmorum* | 4.5 | 2.9 | 4.0 | 0.5 |
| *F. equiseti* | 4.5 | 38.2 | 2.8 | 1.0 |
| *F. graminearum* | 0.0 | 2.9 | 0.0 | 1.0 |
| *F. moniliforme* | 4.5 | 2.9 | 0.5 | 0.5 |
| *F. oxysporum* | 0.0 | 2.9 | 0.0 | 0.5 |
| *F. poae* | 0.0 | 2.9 | 0.0 | 1.0 |
| *F. solani* | 0.0 | 5.9 | 0.0 | 2.0 |
| *H. sativum* | 3.0 | 0.0 | 1.0 | 0.0 |

[a]Based on 66 seed samples in 1985/86 and 34 in 1986/87 season.

[b]Mean of infected samples only. Determined by the deep-freeze blotter method on 200 seeds/sample.

much larger numbers of lots than in 1985/86. Percent seed in which individual fungi were detected were consistently low.

## Effects of Fusarium culmorum Seed and Soil-borne Inoculum

Analyses of variance for this experiment data are summarized in Appendix Tables A1-A5. Except for seedling emergence in 1985/86 and root rot severity index at FGS 10.5.3 in 1986/87, all measured parameters showed a nonsignificant row spacing x source of inoculum interaction. Results, therefore, are presented separately for the main effects of row spacing and inoculum source.

Row spacing had no effect on root rot in the 1985/86 season, but in 1986/87 dryer season, plots with row spacing of 20 cm did have greater root rot severities at FGS 10.5.3 (Table 14). In 1985/86 season, deadhead incidence was significantly greater in plots with row spacing of 20 cm. In 1986/87, this parameter was not affected.

Seed inoculation, either alone, or in combination with soil inoculation drastically reduced seedling emergence in both seasons, reduced straw and grain yield, and increased root rot severity and % deadhead in 1986/87 (Tables 15 and 16). In 1985/86, the few surviving plants died immediately after emergence and no disease ratings and yields were

Table 14. Effect of row spacing on root rot severity at two Feekes' growth stages (FGS) and on deadhead occurrence at FGS 11.1 in the wheat variety Cocorit grown at Sidi El Aydi in 1985/86 and 1986/87 growing seasons

| Row spacing | Root rot severity index[a] | | | | Deadhead (%)[b] | |
|---|---|---|---|---|---|---|
| | 1985/86 | | 1986/87 | | 1985/86 | 1986/87 |
| | FGS8-9 | 10.5.3 | FGS8-9 | 10.5.3 | FGS11.1 | 11.1 |
| 20 cm | 41.0 | 34.8 | 15.4 | 34.5 | 5.6 | 15.6 |
| 40 | 35.6 | 33.0 | 13.8 | 23.9 | 2.1 | 6.6 |
| 60 | 43.1 | 32.0 | 12.3 | 10.3 | 3.5 | 4.0 |
| LSD 0.05[c] | 8.6 ns | 11.9 ns | 4.8 ns | 12.9 | 2.0 | 4.9 |

[a]Expressed on a 0-100 scale with 0= all plants healthy and 100= all plants killed.

[b]Primaturely ripened tillers with bleached ears appearing white in a field otherwise green.

[c]ANOVA summary in Appendix Tables A1 and A2 and ns= nonsignificant at the 0.05 level.

Table 15. Effect of Fusarium culmorum inoculum applied to seed and soil on seedling emergence and crop yields of the wheat variety Cocorit grown at Sidi El Aydi in 1985/86 season

| Inoculum[a] source | Emergence plants/$m^2$ | Straw yield qx/ha | Grain yield qx/ha |
|---|---|---|---|
| None | 86.2 | 32.91 | 17.9 |
| Soil | 88.5 | 33.52 | 13.8 |
| Seed | 2.8 | - | - |
| Seed and soil | 3.3 | - | - |
| LSD 0.05[b] | 4.4 | 3.0 | 3.5 |

[a]Inoculum of a virulent isolate of Fusarium culmorum was applied as indicated.

[b]ANOVA summary in Appendix Tables A3 and A4.

Table 16. Effect of Fusarium culmorum inoculum applied to seed and soil on seedling emergence and crop yields of the wheat variety Cocorit grown at Sidi El Aydi in 1986/87 season

| Inoculum[a] source | Emergence plants/$m^2$ | Straw yield qx/ha | Grain yield qx/ha |
|---|---|---|---|
| None | 69.1 | 21.6 | 7.8 |
| Soil | 71.5 | 21.8 | 6.4 |
| Seed | 14.9 | 8.8 | 1.9 |
| Seed and soil | 13.1 | 11.2 | 2.3 |
| LSD 0.05[b] | 3.2 | 3.3 | 1.0 |

[a]Inoculum of a virulent isolate of Fusarium culmorum was applied as indicated.

[b]ANOVA summary in Appendix Table A5.

Table 17. Effect of Fusarium culmorum inoculum applied to seed and soil on root rot at two Feekes' growth stages (FGS) of the wheat variety Cocorit grown at Sidi El Aydi in 1985/86 and 1986/87 seasons

| Inoculum source[b] | Root rot severity index[a] | | | | Deadhead (%) | |
|---|---|---|---|---|---|---|
| | 1985/86 | | 1986/87 | | 1985/86 | 1986/87 |
| | FGS 8-9 | 10.5.3 | FGS 8-9 | 10.5.3 | FGS 11.1 | 11.1 |
| None | 5.0 | 17.5 | 1.5 | 15.5 | 2.6 | 4.9 |
| Soil | 27.0 | 49.1 | 6.3 | 30.3 | 4.9 | 12.6 |
| Seed | -[c] | - | 25.9 | 30.7 | - | 13.9 |
| Seed & soil | - | - | 21.6 | 28.6 | - | 11.6 |
| LSD 0.05[d] | 6.4 | 9.7 | 5.5 | 9.3 | 1.9 | 5.2 |

[a]Expressed on a 0-100 scale with 0= all plants healthy and 100= all plants killed.

[b]Inoculum of a virulent isolate of Fusarium culmorum was applied as indicated.

[c]Data not taken because of insufficient surviving plant number.

[d]ANOVA summary in Appendix Tables A1 and A2.

obtained. Compared to the uninoculated treatment, soil inoculation alone increased root rot ratings at both growth stages in 1985/86 and at FGS 10.5.3 in 1986/87 (Table 17). This treatment increased deadhead incidence in both seasons. It had no effect, however, on seedling emergence and straw yield, but did slightly reduce grain yield (Tables 15 and 16).

## Effect of Seed Vigor on Root Rot Development

In this experiment, four wheat seedlots with different seed vigor levels were planted in soil inoculated with F. culmorum. Analyses of variance are summarized in Appendix Tables A6-A9. Since row spacing x seed vigor interaction was not significant for any of the measured parameters except for emergence in 1986/87, the results are discussed at the main effect level.

Plants in plots with a row spacing of 20 cm showed the highest root rot severity in 1985/86 only, otherwise, row spacing did not affect this parameter (Table 18). In both seasons deadhead incidence was greater in plots with row spacing of 20 cm.

During both the 1985/86 and 1986/87 seasons, seed vigor had no effect on root rot and deadhead incidence (Table 19). Plant emergence, straw yield, and grain yield were not

Table 18. Effect of row spacing on root rot and % deadhead in wheat variety Cocorit planted at Sidi El Aydi in soil inoculated with Fusarium culmorum in the 1985/86 and 1986/87 seasons

| Season and row spacing[b] | Root rot at FGS[a] | | Deadhead |
|---|---|---|---|
| | 8-9 | 10.5.3 | % |
| 1985/86 | | | |
| 20 cm | 27.9[c] | 51.4 | 26.3[d] |
| 40 | 18.1 | 41.3 | 15.7 |
| 60 | 14.6 | 34.8 | 10.1 |
| LSD0.05[e] | 7.2 | 15.3 | 11.4 |
| 1986/87 | | | |
| 20 cm | 14.5 | 36.1 | 35.7 |
| 40 | 14.8 | 35.8 | 22.9 |
| 60 | 14.6 | 38.8 | 13.0 |
| LSD 0.05[e] | 12.7 | 10.3 | 11.6 |

[a]Feekes' growth stage.

[b]Plant emergence was 144, 69, 46 plants/$m^2$ in 1985/85 and 153, 78, and 51 plants/$m^2$ in 1986/87 for row spacing 20, 40, and 60 cm respectively.

[c]Root rot severity index expressed on a 0-100 scale, with 0= all plants healthy and 100= all plants killed.

[d]At FGS 11.1 with deadhead= prematurely ripened tiller with white ear appearing white in a field otherwise green.

[e]ANOVA summary in Appendix Tables A6 and A7.

Table 19. Effect of seed vigor on root rot and agronomic parameters of the wheat variety Cocorit planted at Sidi El Aydi in soil inoculated with Fusarium culmorum in 1985/86 and 1986/87 seasons

| Season and seed vigor[b] | Root rot at FGS[a] 8-9 | Root rot at FGS[a] 10.5.3 | Deadhead (%) | Emergence plants/$m^2$ | Straw yield qx/ha | Grain yield qx/ha |
|---|---|---|---|---|---|---|
| 1985/86 | | | | | | |
| 22.4 mg | 19.0[c] | 43.3 | 19.9[d] | 99.1 | 28.0 | 9.3 |
| 20.0 | 21.0 | 45.1 | 16.2 | 85.9 | 24.3 | 9.3 |
| 19.7 | 19.0 | 38.9 | 15.5 | 87.6 | 25.5 | 9.6 |
| 17.4 | 21.8 | 42.6 | 17.8 | 74.0 | 21.6 | 7.3 |
| LSD0.05[e] | 10.0 | 10.6 | 5.0 | 9.1 | 3.5 | 1.3 |
| 1986/87 | | | | | | |
| 17.6 mg | 14.3 | 40.8 | 22.5 | 99.8 | 22.2 | 6.5 |
| 15.9 | 14.7 | 33.9 | 23.3 | 85.1 | 23.4 | 6.5 |
| 10.6 | 17.2 | 36.7 | 25.3 | 88.6 | 22.5 | 6.3 |
| 19.9 | 12.4 | 36.2 | 24.2 | 103.1 | 23.4 | 6.6 |
| LSD0.05[e] | 7.6 | 14.4 | 5.6 | 7.2 | 2.7 | 1.0 |

[a]Feekes' growth stage.

[b]Determined by the seedling growth rate test (AOSA, 1983) where seedling weight is given in mg.

[c]Root rot severity index expressed on a 0-100 scale, with 0= all plants healthy and 100= all plants killed.

[d]At FGS 11.1 with deadhead= prematurely ripened tiller with white ear appearing white in a field otherwise green.

[e]ANOVA summary in Appendix Tables A6-A9.

affected by seed vigor in 1986/87, however, in 1985/86 the lowest seed vigor produced the lowest plant emergence and grain yield.

## Effect of Root Rot Pathogens on Disease Development and Agronomic Performance of Four Wheat Varieties

In this experiment, inoculum of F. culmorum and H. sativum (P), variety (V) and row spacing (RS) were the main effects. First-order interactions of RS x P and V x P are discussed whenever they are significant (Appendix Tables A10-A14). In one instance where the second-order interaction RS x V x P was significant (Appendix Table A11), the interaction V x P is discussed at each row spacing level.

### Effect on root rot severity

This parameter was measured only in 1986/87. Row spacing had no effect on root rot severity index of plants in uninoculated and H. sativum inoculated plots (Table 20) at any growth stage. In F. culmorum inoculated plots, root rot severity tended to increase significantly as row spacings increased.

Both H. sativum and F. culmorum caused significant increase in root rot severity as plant growth stage progressed. Disease severity was similar for these two

pathogens at FGS 8-9 in plots with row spacing of 20 and 40 cm but for later growth stages at all row spacings F. culmorum was consistently more virulent.

Similar levels of root rot occurred on plants in uninoculated plots for all varieties at any growth stage (Table 21). Significantly greater root rot was caused by either H. sativum or F. culmorum for all varieties at all growth stages except for Karim at FGS 10.5.3 (mid-flowering stage) and for Marzak and Karim at FGS 11.1 (Milky ripe stage) which were not affected by H. sativum. There was no difference in root rot severity caused by these two pathogens at FGS 8-9 (mid-stem extension stage) with all varieties except Karim which developed greater disease severity in the F. culmorum plots. At FGS 10.5.3 and FGS 11.1, F. culmorum induced higher disease severities with all varieties except Kyperounda at FGS 10.5.3. In general, Cocorit appeared to be very susceptible to F. culmorum and moderately susceptible to F. sativum. The other three varieties were moderately susceptible to F. culmorum and less susceptible to H. sativum.

Effect on deadhead occurrence

In the 1985/86 and 1986/87 growing seasons, % deadhead in uninoculated plots showed overall mean values of 2.3 and

Table 20. Effect of row spacing on root rot severity at three different growth stages in wheat plots inoculated with Fusarium culmorum and Helminthosporium sativum and grown at Sidi El Aydi in 1986/87 season

| Growth stage[a] and pathogen | Row spacing (cm) 20 | 40 | 60 | LSD 0.05[b] |
|---|---|---|---|---|
| FGS 8-9 | | | | |
| Uninoculated | 7.8[c] | 4.7 | 4.3 | 7.7 |
| H. sativum[d] | 21.4 | 18.9 | 17.1 | 7.7 |
| F. culmorum[d] | 18.1 | 23.5 | 32.5 | 7.7 |
| LSD 0.05[b] | 7.4 | 7.4 | 7.4 | |
| FGS 10.5.3 | | | | |
| Uninoculated | 11.3 | 11.1 | 7.9 | 7.8 |
| H. sativum | 20.8 | 24.5 | 24.0 | 7.8 |
| F. culmorum | 39.0 | 48.2 | 56.2 | 7.8 |
| LSD 0.05[b] | 7.5 | 7.5 | 7.5 | |
| FGS 11.1 | | | | |
| Uninoculated | 13.8 | 11.6 | 18.3 | 9.9 |
| H. sativum | 33.7 | 34.1 | 35.2 | 9.9 |
| F. culmorum | 49.1 | 70.1 | 60.5 | 9.9 |
| LSD 0.05[b] | 10.2 | 10.2 | 10.2 | |

[a]FGS= Feekes' growth stage.

[b]ANOVA summary in Appendix Table A10.

[c]Root rot severity index expressed on 0-100 scale; 0= all plants healthy and 100= all plants killed.

[d]Both seed and soil were inoculated.

Table 21. Effect of *Fusarium culmorum* and *Helminthosporium sativum* on root rot development at three different growth stages of four wheat varieties grown at Sidi El Aydi during 1986/87 season

| Growth stage[a] and pathogen | Variety | | | | |
|---|---|---|---|---|---|
| | Cocorit | Marzak | Karim | Kyperounda | LSD 0.05[b] |
| FGS 8-9 | | | | | |
| Uninoculated | 6.3[c] | 4.7 | 3.8 | 7.5 | 7.3 |
| *H. sativum*[d] | 28.4 | 15.7 | 13.8 | 18.7 | 7.3 |
| *F. culmorum*[d] | 26.1 | 22.2 | 25.3 | 25.2 | 7.3 |
| LSD 0.05[b] | 8.6 | 8.6 | 8.6 | 8.6 | |
| FGS 10.5.3 | | | | | |
| Uninoculated | 8.7 | 10.1 | 8.7 | 13.0 | 9.1 |
| *H. sativum* | 36.7 | 24.3 | 9.7 | 21.7 | 9.1 |
| *F. culmorum* | 93.3 | 35.0 | 33.9 | 28.8 | 9.1 |
| LSD 0.05[b] | 8.7 | 8.7 | 8.7 | 8.7 | |
| FGS 11.1 | | | | | |
| Uninoculated | 16.5 | 16.8 | 13.1 | 11.8 | 10.6 |
| *H. sativum* | 54.7 | 24.5 | 22.1 | 36.0 | 10.6 |
| *F. culmorum* | 80.6 | 46.0 | 51.7 | 61.3 | 10.6 |
| LSD 0.05[b] | 11.8 | 11.8 | 11.8 | 11.8 | |

[a]FGS= Feekes' growth stage.

[b]ANOVA summary in Appendix Table A10.

[c]Root rot severity expressed on 0-100 scale; 0= all plants healthy and 100= all plants killed.

[d]Both seed and soil were inoculated.

10.3%, respectively (Tables 22 and 23). There were no differences in these plots among row spacings and varieties.

In the 1985/86 season, Kyperounda showed a significantly higher percentage of deadhead compared to the other varieties at row spacings of 20 and 40 cm with both H. sativum and F. culmorum (Table 22). Marzak and Karim had significantly lower deadhead incidences than the other varieties at the 20 cm row spacing in F. culmorum plots only. In row spacing of 60 cm, none of the main effects tested was significant for this parameter.

In 1986/87, H. sativum had no effect on % deadhead with all row spacings and varieties (Table 23). In F. culmorum inoculated plots, a significant increase in % deadhead occurred at all row spacings with Cocorit and at row spacing 60 cm with Karim.

Effect on emergence

In 1985/86, emergence counts in uninoculated plots ranged from 55.6 plants/$m^2$ for the 60 cm row spacing to 171.1 plants/$m^2$ for 20 cm (Table 24), while in 1986/87, these counts were 33.3 and 100.3, respectively (Table 25). In both cropping seasons, H. sativum and F. culmorum effects on emergence were not affected by row spacings with one exception in 1985/86 where H. sativum caused less damage at

Table 22. Effect of Helminthosporium sativum and Fusarium culmorum on deadhead incidence at FGS 11.1 in four wheat varieties grown at Sidi El Aydi in 1985/86 season

| Row spacing and variety | % deadhead[a] | | | |
|---|---|---|---|---|
| | Uninoculated | H. sativum | F. culmorum | LSD 0.05[b] |
| 20 cm | | | | |
| Cocorit | 3.8 | 5.1 | 10.8 | 14.3[c] |
| Marzak | 2.4 | 0.6 | 25.7 | |
| Karim | 3.6 | 1.9 | 25.4 | |
| Kyperounda | 3.5 | 30.6 | 44.5 | |
| LSD0.05[b] | 16.2 | 16.2 | 16.2 | |
| Mean[e] | 3.3 | 9.6 | 26.6 | 3.6[d] |
| 40 cm | | | | |
| Cocorit | 1.9 | 1.4 | 7.9 | 14.3[c] |
| Marzak | 1.3 | 0.9 | 5.7 | |
| Karim | 2.3 | 1.4 | 7.5 | |
| Kyperounda | 4.2 | 21.7 | 24.2 | |
| LSD0.05[b] | 16.2 | 16.2 | 16.2 | |
| Mean[e] | 2.4 | 6.3 | 11.3 | 3.6[d] |
| 60 cm | | | | |
| Cocorit | 0.9 | 2.1 | 9.5 | 14.3[c] |
| Marzak | 0.5 | 0.2 | 4.4 | |
| Karim | 0.9 | 1.7 | 9.4 | |
| Kyperounda | 2.5 | 5.2 | 14.0 | |
| LSD0.05[b] | 16.2 | 16.2 | 16.2 | |
| Mean[e] | 1.2 | 2.3 | 9.3 | 3.6[d] |
| Overall mean | 2.3 | 6.1 | 15.7 | |

[a]Tillers prematurely ripened with bleached ears appearing white in a field otherwise green.

[b]ANOVA summary in Appendix Table A11.

[c]For any comparison at same variety level.

[d]For any comparison of treatment mean at same row spacing level.

[e]LSD0.05 values for comparison of row spacing means at same pathogen level is 6.9.

Table 23. Effect of *Helminthosporium sativum* and *Fusarium culmorum* on deadhead incidence at FGS 11.1 in four wheat varieties grown at Sidi El Aydi in 1986/87 season

| Row spacing and variety | % deadheads[a] | | | |
|---|---|---|---|---|
| | Uninoculated | *H. sativum* | *F. culmorum* | LSD0.05[b] |
| *20 cm* | | | | |
| Cocorit | 14.5 | 12.5 | 60.0 | 15.1[c] |
| Marzak | 9.0 | 12.5 | 17.3 | |
| Karim | 11.5 | 17.0 | 18.0 | |
| Kyperounda | 22.5 | 24.3 | 35.3 | |
| LSD0.05[b] | 18.1 | 18.1 | 18.1 | |
| Mean[e] | 14.4 | 23.1 | 32.6 | 3.8[d] |
| *40 cm* | | | | |
| Cocorit | 8.7 | 15.3 | 40.0 | 15.1[c] |
| Marzak | 7.0 | 15.3 | 14.3 | |
| Karim | 8.5 | 14.8 | 22.5 | |
| Kyperounda | 10.0 | 23.0 | 24.3 | |
| LSD0.05[b] | 18.1 | 18.1 | 18.1 | |
| Mean[e] | 8.6 | 19.3 | 25.3 | 3.8[d] |
| *60 cm* | | | | |
| Cocorit | 8.0 | 8.3 | 85.5 | 15.1[c] |
| Marzak | 4.0 | 8.3 | 14.3 | |
| Karim | 12.3 | 12.3 | 82.8 | |
| Kyperounda | 7.5 | 20.0 | 21.8 | |
| LSD0.05[b] | 18.1 | 18.1 | 18.1 | |
| Mean[e] | 7.9 | 16.1 | 51.1 | 3.7[d] |
| Overall mean | 10.3 | 19.5 | 36.3 | |

[a]Tillers prematurely ripened with bleached ears appearing white in a field otherwise green.

[b]ANOVA summary in Appendix Table A11.

[c]For any comparison at same variety level.

[d]For any comparison of treatment means at same row spacing level.

[e]LSD0.05 values for comparison of row spacing means at the same pathogen level is 7.0.

Table 24. Effect of Helminthosporium sativum and Fusarium culmorum on seedling emergence of four wheat varieties grown at Sidi El Aydi in 1985/86 season

| Row spacing and variety | Uninoculated plant/$m^2$ | % reduction[a] due to: | | |
|---|---|---|---|---|
| | | H. sativum | F. culmorum | LSD0.05[b] |
| Row spacing (cm) | | | | |
| 20 | 171.1 | 10.5 | 66.9 | 5.1[c] |
| 40 | 82.3 | 5.8 | 68.8 | |
| 60 | 55.6 | 9.5 | 69.1 | |
| LSD0.05[b] | 5.5 | 3.2 | 3.2 | |
| Variety | | | | |
| Cocorit | 102.9 | 1.5 | 85.7 | 5.9[d] |
| Marzak | 105.1 | 1.0 | 64.5 | |
| Karim | 99.1 | 0.5 | 66.5 | |
| Kyperounda | 104.8 | 31.5 | 56.3 | |
| LSD0.05[b] | 5.9 | 5.1 | 5.1 | |

[a]%= 100 X (inoculated- uninoculated) / uninoculated.

[b]ANOVA summary in Appendix Table A12.

[c]For any comparison of the two pathogens at the same row spacing level.

[d]For any comparison of the two pathogens at the same variety level.

Table 25. Effect of Helminthosporium sativum and Fusarium culmorum on seedling emergence of four wheat varieties grown at Sidi El Aydi in 1986/87 season

| Row spacing and variety | Uninoculated plant/m$^2$ | % reduction[a] due to: H. sativum | F. culmorum | LSD0.05[b] |
|---|---|---|---|---|
| Row spacing (cm) | | | | |
| 20 | 100.3 | 28.6 | 87.3 | 6.2[c] |
| 40 | 52.0 | 27.0 | 86.0 | |
| 60 | 33.3 | 28.6 | 86.4 | |
| LSD0.05[b] | 4.4 | 4.7 | 4.7 | |
| Variety | | | | |
| Cocorit | 57.8 | 55.1 | 97.1 | 7.2[d] |
| Marzak | 62.9 | 16.6 | 76.5 | |
| Karim | 51.2 | 13.7 | 87.2 | |
| Kyperounda | 75.5 | 26.7 | 85.4 | |
| LSD0.05[b] | 4.9 | 7.8 | 7.8 | |

[a]%= 100 X (inoculated - uninoculated)/uninoculated.

[b]ANOVA summary in Appendix Table A12.

[c]For any comparison of the two pathogens at the same row spacing level.

[d]For any comparison of the two pathogens at the same variety level.

row spacing 40 cm. Also, F. culmorum was consistently more damaging than H. sativum.

In 1985/86, emergence in uninoculated plots ranged from 99.1 for Karim to 105.1 plants/$m^2$ for Marzak (Table 24). While H. sativum reduced plant emergence for Kyperounda only, F. culmorum significantly reduced it for all varieties with Cocorit most severely affected followed by Marzak and Karim then Kyperounda. In 1986/87, emergence in the uninoculated treatment ranged from 51.2 plants/$m^2$ for Karim to 75.5 for Kyperounda with no significant difference between any two varieties (Table 25). Helminthosporium sativum significantly reduced emergence counts for all varieties with Cocorit showing the greatest reduction followed by Kyperounda then Marzak and Karim. Fusarium culmorum caused a drastic reduction in emergence for all varieties with Cocorit again most severely affected followed by Karim and Kyperounda then Marzak.

Effect on straw yield

In the uninoculated plots, straw yield ranged from 44.1 to 56.5 and from 14.7 to 17.8 qx/ha in 1985/86 and 1986/87 respectively with the lowest yield obtained with the 60 cm row spacing (Tables 26 and 27). In both seasons, H. sativum had no effect on this yield at all three row spacings, but F.

culmorum caused significant reductions with the amount of loss tending to increase as row spacing increased.

In 1985/86, straw yield in uninoculated plots ranged from 44.0 qx/ha for Marzak to 60.1 qx/ha for Kyperounda (Table 27). There was no difference in straw yield among the semi-dwarf varieties Cocorit, Marzak and Karim but Kyperounda, a tall variety, produced a significantly greater amount. Helminthosporium sativum had no effect on straw yield of the tested varieties except Marzak which showed a significant increase. Fusarium culmorum significantly reduced this value for all varieties with Cocorit showing the greatest loss followed by Marzak and Karim then Kyperounda, which was the least affected.

In 1986/87, straw yield in the uninoculated plots ranged from 12.3 qx/ha for Karim to 22.2 qx/ha for Kyperounda (Table 27). There was no significant difference in yield between Cocorit and Marzak but Kyperounda was significantly greater than both. Helminthosporium sativum caused a significant reduction with Cocorit only. Fusarium culmorum significantly reduced straw yield for all varieties with Cocorit being the most affected and the other three varieties showing smaller reduction.

In both the 1985/86 and 1986/87 seasons, F. culmorum was more damaging to straw yield than was H. sativum.

Table 26. Effect of Helminthosporium sativum and Fusarium culmorum on straw yield of four wheat varieties grown at Sidi El Aydi in 1985/86 season

| Row spacing and variety | Uninoculated qx/ha | % reduction(-)/increase(+) due to: H. sativum | F. culmorum | LSD0.05[a] |
|---|---|---|---|---|
| Row spacing (cm) | | | | |
| 20 | 56.5 | +7.2[b] | -28.4 | 10.7[c] |
| 40 | 51.1 | +2.8 | -42.8 | |
| 60 | 44.1 | +6.8 | -49.6 | |
| LSD0.05[a] | 5.9 | 8.5 | 8.5 | |
| Variety | | | | |
| Cocorit | 48.6 | -0.2 | -70.2 | 12.3[d] |
| Marzak | 44.0 | +17.9 | -34.1 | |
| Karim | 49.5 | +0.3 | -40.5 | |
| Kyperounda | 60.1 | +4.5 | -15.7 | |
| LSD0.05[a] | 6.1 | 13.1 | 13.1 | |

[a]ANOVA summary in Appendix Table A13.

[b]%= 100 X (inoculated - uninoculated)/uninoculated.

[c]For comparison within a cropping season of the two pathogens at any same row spacing level.

[d]For comparison within a cropping season of the two pathogens at any same variety level.

Table 27. Effect of Helminthosporium sativum and Fusarium culmorum on straw yield of four wheat varieties grown at Sidi El Aydi in 1986/87 season

| Row spacing and variety | Uninoculated qx/ha | % reduction(-)/increase(+) due to: H. sativum | F. culmorum | LSD 0.05[a] |
|---|---|---|---|---|
| Row spacing (cm) | | | | |
| 20 | 16.8 | +5.8[b] | -27.2 | 14.2[c] |
| 40 | 17.8 | -12.0 | -56.7 | |
| 60 | 14.7 | -9.9 | -62.8 | |
| LSD0.05[a] | 2.6 | 14.0 | 14.0 | |
| Variety | | | | |
| Cocorit | 16.2 | -18.8 | -84.1 | 16.3[d] |
| Marzak | 15.2 | -18.1 | -32.0 | |
| Karim | 12.3 | 14.8 | -43.1 | |
| Kyperounda | 22.2 | +0.6 | -36.4 | |
| LSD0.05[a] | 2.8 | 18.8 | 18.8 | |

[a]ANOVA summary in Table A13.

[b]%= 100 X (inoculated - uninoculated)/uninoculated.

[c]For comparison within a cropping season of the two pathogens at any same row spacing level.

[d]For comparison within a cropping season of the two pathogens at any same variety level.

Effect on grain yield

In the uninoculated plots, overall grain yield means were 24.6 and 5.5 qx/ha in the 1985/86 and 1986/87 seasons respectively (Tables 28 and 29). There was no row spacing effect in either season. In 1985/86, H. sativum had no effect on grain yield with the row spacings of 20 and 60 cm but caused a significant reduction in the 40 cm spacings (Table 28). Fusarium culmorum, however, induced significantly greater yield reductions with no difference between row spacings. In 1986/87, H. sativum caused significant yield reduction only in plots with row spacing of 60 cm (Table 29). Fusarium culmorum induced significant yield loss with allthree row spacings and the greatest loss occurred at row spacing 40 cm and 60 cm. Again in both seasons, F. culmorum was more damaging than H. sativum.

In 1985/86, grain yield ranged from 17.5 qx/ha for Kyperounda to 31.4 for Karim (Table 28). Helminthosporium sativum had no effect on grain yield of the tested varieties except for Kyperounda where it was greatly reduced. However, F. culmorum caused significant yield reduction in all varieties with the greatest loss observed with Cocorit followed by the other three varieties with no difference between them. In 1986/87, grain yield in uninoculated plots ranged from 4.1 qx/ha for Kyperounda to 7.2 qx/ha for Marzak

(Table 29). Helminthosporium sativum affected none of the tested varieties. Fusarium culmorum induced significant reductions in all these varieties with the greatest loss exhibited by Cocorit followed by Karim then Marzak and Kyperounda.

## Effects of Fusarium culmorum Natural and Artificial Seed-borne Inoculum

### Effect of natural seed infection

Seed health tests showed low levels of F. culmorum natural seed infection in the seedlots of the four different wheat varieties grown in this field test (Table 30). Seed treatment with the fungicide Thiabendazole (TBZ) eliminated all detectable seed infection in all lots.

No relationship was found between root rot severity indices and natural seed infection levels when these seedlots were planted in four locations in 1986/87 (Table 31). Generally this relationship was consistent across all test locations and all varieties except for Marzak at Sidi El Aydi where the lowest levels of root rot severity was associated with the highest level of seed infection.

TBZ seed treatment of naturally infected seed reduced the isolation frequency of F. culmorum from the roots of

Table 28. Effect of Helminthosporium sativum and Fusarium culmorum on grain yield of four wheat varieties grown at Sidi El Aydi in 1985/86 season

| Row spacing and variety | Uninoculated qx/ha | % reduction(-)/increase(+) due to: H. sativum | F. culmorum | LSD 0.05[a] |
|---|---|---|---|---|
| Row spacing (cm) | | | | |
| 20 | 25.4 | +1.3[b] | -60.8 | 11.5[c] |
| 40 | 25.6 | -13.2 | -64.9 | |
| 60 | 22.8 | -4.3 | -67.3 | |
| LSD0.05[a] | 3.2 | 10.8 | 10.8 | |
| Mean | 24.6 | | | |
| Variety | | | | |
| Cocorit | 23.7 | +5.1 | -82.0 | 13.3[d] |
| Marzak | 25.9 | +7.7 | -52.9 | |
| Karim | 31.4 | +4.8 | -55.1 | |
| Kyperounda | 17.5 | -39.1 | -67.3 | |
| LSD0.05[a] | 3.4 | 14.1 | 14.1 | |

[a]ANOVA summary in Appendix Table A14.

[b]%= 100 X (inoculated - uninoculated)/uninoculated.

[c]For comparison of the two pathogens at the same row spacing level.

[d]For comparison of the two pathogens at the same variety level.

Table 29. Effect of Helminthosporium sativum and Fusarium culmorum on grain yield of four wheat varieties grown at Sidi El Aydi in 1985/86 season

| Row spacing and variety | Uninoculated qx/ha | % reduction(-)/increase(+) due to: H. sativum | F. culmorum | LSD 0.05[a] |
|---|---|---|---|---|
| Row spacing (cm) | | | | |
| 20 | 6.1 | -4.5[b] | -47.7 | 36.2[c] |
| 40 | 5.9 | -7.3 | -76.2 | |
| 60 | 4.7 | -28.3 | -81.3 | |
| LSD0.05[a] | 1.4 | 20.6 | 20.6 | |
| Mean | 5.5 | | | |
| Variety | | | | |
| Cocorit | 5.3 | -22.0 | -94.6 | 41.8[d] |
| Marzak | 7.2 | -8.4 | -53.3 | |
| Karim | 5.5 | +8.0 | -71.5 | |
| Kyperounda | 4.1 | -31.1 | -54.1 | |
| LSD0.05[a] | 1.4 | 43.3 | 43.3 | |

[a]ANOVA summary in Appendix Table A14.

[b]%= 100 X (inoculated - uninoculated)/uninoculated.

[c]For comparison of the two pathogens at the same row spacing level.

[d]For comparison of the two pathogens at the same variety level.

Table 30. *Fusarium culmorum* seed infection in uninoculated seedlots of wheat used in 1986/87 season to investigate the effects of *F. culmorum* natural seed-borne inoculum on root rot development

| | Percent infected seed[a] | |
|---|---|---|
| Variety[b] | Untreated | Treated[c] |
| Cocorit | 0.0 | 0.0 |
| | 1.0 | 0.0 |
| | 1.0 | 0.0 |
| | 4.0 | 0.0 |
| | 4.0 | 0.0 |
| | 8.0 | 0.0 |
| Marzak | 3.0 | 0.0 |
| | 6.0 | 0.0 |
| Karim | 3.0 | 0.0 |
| | 4.0 | 0.0 |
| Kyperounda | 0.0 | 0.0 |
| | 2.0 | 0.0 |
| Average | 3.4 | 0.0 |

[a]Determined with deep-freeze method where 200 seeds per seedlot were tested.

[b]A total of 6 seedlots was used for Cocorit and 2 each for Marzak, Karim and Kyperounda.

[c]Treated with the fungicide Thiabendazole at the rate of 100 g a.i./100 kg seed.

Table 31. Effect of Fusarium culmorum natural seed infection on root rot severity at FGS 10.5.3 in four wheat varieties grown in four locations in West Central Morocco in 1986/87 season

| Variety | % Seed infection | Location | | | |
|---|---|---|---|---|---|
| | | Sidi El Aydi | Khemis Zemamra | Jemaa Shaim | Tessaout |
| Cocorit | 0.0[a] | 5.6[b] | 14.1 | 9.4 | 2.7 |
| | 1.0 | 7.8 | 13.9 | 8.0 | 4.4 |
| | 1.0 | 6.3 | 15.4 | 6.7 | 7.4 |
| | 4.0 | 3.3 | 14.2 | 8.2 | 6.2 |
| | 4.0 | 5.7 | 10.6 | 4.9 | 4.1 |
| | 8.0 | 5.6 | 7.7 | 5.3 | 11.3 |
| Marzak | 3.0 | 14.5 | 10.7 | 6.9 | 4.8 |
| | 6.0 | 5.9 | 14.1 | 8.3 | 5.2 |
| Karim | 3.0 | 10.8 | 11.0 | 8.1 | 6.5 |
| | 4.0 | 5.1 | 15.5 | 6.5 | 4.9 |
| Kyperounda | 0.0 | 8.9 | 14.4 | 13.4 | 6.3 |
| | 2.0 | 5.6 | 12.9 | 14.2 | 6.9 |
| LSD 0.05[c] | 6.8 | 8.1 | 8.7 | 13.1 | 13.1 |

[a] Determined with the deep-freeze method by testing 200 seeds per seedlot. Each value corresponds to a different wheat seedlot.

[b] Root rot severity index (RRSI) expressed on a 0-100 scale using the formula:

$$RRSI = \frac{\text{Sum of individual plant numerical root rot ratings} \times 100}{\text{Number of plants examined} \times 5}$$

with the numerical ratings of 0= no infection, 1= small, scattered lesions on subcrown internode or roots, and 5= plant killed.

[c] ANOVA summary in Appendix Table A15.

diseased plants at all locations but did not eliminate it (Table 32). Seed treatment also significantly reduced root rot severity at Khemis Zemamra but had no effect at the other locations. The incidence of deadheads was not affected by TBZ seed treatment at the two locations where this was measured (Table 32). Seed treatment significantly increased emergence at all locations but had no effect on either straw or grain yields (Table 33).

Effect of artificial seed inoculation

Effect on disease parameters. Infection levels ranged from 80 to 100% in the four seedlots inoculated with F. culmorum (Table 34). TBZ seed treatment eradicated this infection in all lots. Plots planted with inoculated untreated seed showed high isolation frequency of F. culmorum from diseased plants at all locations with the highest levels observed at Sidi El Aydi and Jemaa Shaim and the lowest at Khemis Zemamra (Table 35). TBZ seed treatment reduced this infection in all locations.

Seed inoculation with F. culmorum resulted in high root rot severity index at all locations and in all varieties (Table 36). Cocorit showed the lowest level of this parameter at Sidi El Aydi, Khemis Zemamra and Jemaa Shaim.

Table 32. Effect of Thiabendazole seed treatment[a] on root infection, root rot severity, and % deadhead in plots planted with Fusarium culmorum naturally infected seed and grown in four locations in West Central Morocco in 1986/87 season. Values are averaged over all seedlots

| Parameters and treatment | Location | | | |
|---|---|---|---|---|
| | Sidi El Aydi | Khemis Zemamra | Jemaa Shaim | Tessaout |
| % Isolation from root[b] | | | | |
| Untreated | 0.9 | 21.4 | 2.9 | 6.1 |
| Treated | 0.0 | 14.0 | 1.8 | 2.4 |
| Difference | 0.9 | -7.4 | -1.1 | -3.7 |
| Root rot index(%)[c] | | | | |
| Untreated | 7.1 | 12.9 | 8.3 | 5.9 |
| Treated | 8.2 | 9.9 | 7.5 | 5.0 |
| Difference[d] | 1.1ns | -3.0* | -1.2ns | -1.9ns |
| % Deadhead[e] | | | | |
| Untreated | 7.2 | - | - | 8.4 |
| Treated | 5.2 | - | - | 6.8 |
| Difference[d] | -2.0ns | - | - | -2.4ns |

[a]Seed treated with Thiabendazole at the rate of 100 g a.i./ 100 kg seed.

[b]% plants from which the fungus was isolated by planting on PDA of 5-mm root segments from each plant with individual root rot rating greater than 0.

[c]Root rot severity index evaluated at wheat Feekes' growth stage 10.5.3 and expressed on a 0-100 scale.

[d]Difference ns= nonsignificant, *= significant at P= 0.05 and **= significant at P= 0.01. ANOVA summary is given in Appendix Tables A15 and A16.

[e]% deadhead evaluated at wheat Feekes' growth stage 11.1 with a deadhead= tiller prematurely ripened with a bleached ear appearing white in a field otherwise green.

Table 33. Effect of Thiabendazole seed treatment[a] on plant emergence and crop yield in wheat pots planted with Fusarium culmorum naturally infected seed and grown in four locations in West Central Morocco in 1986/87 season. Values are averaged over all seedlots

| Parameters and treatment | Location | | | |
|---|---|---|---|---|
| | Sidi El Aydi | Khemis Zemamra | Jemaa Shaim | Tessaout |
| Emergence(plants/$m^2$) | | | | |
| Untreated | 99.6 | 96.8 | 113.5 | 79.0 |
| Treated | 119.9 | 122.8 | 137.1 | 89.0 |
| Difference[b] | 20.3** | 26.0** | 23.6** | 10.0** |
| Straw yield(qx/ha) | | | | |
| Untreated | 19.5 | 5.5 | 9.4 | 21.5 |
| Treated | 19.6 | 6.5 | 8.9 | 22.0 |
| Difference[b] | 0.1ns | 1.0ns | -0.5ns | 0.5ns |
| Grain yield(qx/ha) | | | | |
| Untreated | 8.2 | 0.6 | 3.9 | 8.6 |
| Treated | 8.1 | 0.6 | 3.7 | 9.4 |
| Difference[b] | -0.1ns | 0.0ns | -0.2ns | 0.8ns |

[a]Seed treated with Thiabendazole at the rate of 100 g a.i./ 100kg seed.

[b]Difference ns= nonsignificant, *= significant at P= 0.05 and **= significant at P= 0.01. ANOVA summary given in Appendix Tables A17-A19.

Table 34. *Fusarium culmorum* seed infection in inoculated wheat seedlots used in 1986/87 season to investigate the effects of *F. culmorum* artificial seed-borne inoculum on root rot development

| | % Seed in which the fungus was detected[a] | |
|---|---|---|
| Variety[b] | Untreated | Treated[c] |
| Cocorit | 80.0 | 0.0 |
| Marzak | 96.0 | 0.0 |
| Karim | 100.0 | 0.0 |
| Kyperounda | 99.0 | 0.0 |
| Average | 93.8 | 0.0 |

[a]Determined with deep-freeze method where 200 seeds per seedlot were tested.

[b]One seedlot per variety was inoculated with a spore suspension of *F. culmorum*.

[c]Treated with the fungicide Thiabendazole at the rate of 100 g a.i./100 kg seed.

Table 35. Effect of Fusarium culmorum seed inoculation and Thiabendazole seed treatment on isolation frequency of F. culmorum from root of diseased plants of four wheat varieties grown in four locations in West Central Morocco in 1986/87 season

| Locations and varieties | Inoculated[a] | | |
|---|---|---|---|
| | Untreated | Treated[b] | Difference |
| Sidi El Aydi | | | |
| Cocorit | 54.9[c] | 0.0 | -54.9 |
| Marzak | 82.3 | 0.8 | -81.5 |
| Karim | 84.2 | 0.0 | -84.2 |
| Kyperounda | 70.0 | 0.0 | -70.0 |
| Mean | 72.9 | 0.0 | -72.9 |
| Khemis Zemamra | | | |
| Cocorit | 25.7 | 9.4 | -16.3 |
| Marzak | 42.1 | 18.8 | -23.3 |
| Karim | 59.2 | 9.5 | -49.7 |
| Kyperounda | 48.9 | 7.4 | -41.5 |
| Mean | 44.0 | 11.3 | -32.7 |
| Jemaa Shaim | | | |
| Cocorit | 48.0 | 1.3 | -46.7 |
| Marzak | 90.0 | 3.0 | -87.0 |
| Karim | 76.0 | 2.9 | -73.1 |
| Kyperounda | 76.0 | 1.6 | -74.4 |
| Mean | 72.5 | 2.3 | -70.2 |
| Tessaout | | | |
| Cocorit | 78.7 | 2.5 | -76.2 |
| Marzak | 58.7 | 7.5 | -51.2 |
| Karim | 34.7 | 0.0 | -34.7 |
| Kyperounda | 69.6 | 18.2 | -51.4 |
| Mean | 60.4 | 7.1 | -53.3 |

[a]Seed inoculated with a spore suspension of F. culmorum.

[b]Seed treated with Thiabendazole at a rate of 100 g a.i./100 kg seed.

[c]% of plants from which the fungus was isolated by plating on PDA of 5-mm root segments of each plant showing a numerical root rot rating >0.

Table 36. Effect of Fusarium culmorum seed inoculation and Thiabendazole seed treatment on root rot of four wheat varieties grown in four locations in West Central Morocco in 1986/87 season

| Locations and varieties | Inoculated[a] | | |
|---|---|---|---|
| | Untreated | Treated[b] | Difference[c] |
| Sidi El Aydi | | | |
| Cocorit | 24.3[d] | 14.6 | -9.7 ** |
| Marzak | 52.8 | 3.9 | -48.9 ** |
| Karim | 52.1 | 6.4 | -45.7 ** |
| Kyperounda | 57.6 | 8.8 | -48.8 ** |
| LSD 0.05[e] | 6.8 | 6.8 | 9.6 |
| Khemis Zemamra | | | |
| Cocorit | 16.9 | 11.4 | -5.5 |
| Marzak | 16.4 | 9.6 | -6.8 |
| Karim | 34.9 | 11.0 | -23.9 ** |
| Kyperounda | 26.3 | 13.3 | -13.0 ** |
| LSD 0.05[e] | 8.1 | 8.1 | 11.5 |
| Jemaa Shaim | | | |
| Cocorit | 14.4 | 6.7 | -7.7 |
| Marzak | 45.8 | 10.9 | -34.9 ** |
| Karim | 44.2 | 8.4 | -35.8 ** |
| Kyperounda | 38.7 | 11.3 | -27.4 ** |
| LSD 0.05[e] | 8.7 | 8.7 | 12.3 |
| Tessaout | | | |
| Cocorit | 49.1 | 7.3 | -41.8 ** |
| Marzak | 26.9 | 6.7 | -20.2 ** |
| Karim | 14.4 | 2.4 | -12.0 |
| Kyperounda | 36.7 | 10.2 | -26.5 ** |
| LSD 0.05[e] | 13.0 | 13.0 | 18.5 |

[a]Seed inoculated with a suspension of F. culmorum.

[b]Seed treated with Thiabendazole at a rate of 100 g a.i./100 kg seed.

[c]Contrasts between treatment means significant at *= P= 0.05, **= P= 0.01 (Appendix Table A15).

[d]Root rot severity index evaluated at wheat Feekes' growth stage 10.5.3 and expressed on a 0-100 scale.

[e]ANOVA summary in Appendix Table A15.

At these three locations, Marzak, Karim and Kyperounda tended to show equal levels of root rot but at Tessaout, Cocorit and Kyperounda developed significantly higher levels and Karim had the lowest. TBZ seed treatment caused a significant reduction in root rot at all locations and in all varieties except in Cocorit and Marzak at Khemis Zemamra and Karim at Tessaout.

Artificial inoculation resulted in high % deadhead in all varieties at Sidi El Aydi, and in Marzak and Kyperounda at Tessaout (Table 37). TBZ seed treatment significantly reduced this parameter in all varieties at Sidi El Aydi and in Kyperounda at Tessaout.

Effect on agronomic parameters Artificial inoculation with F. culmorum drastically reduced emergence at all locations and in all varieties. No difference was observed in emergence between varieties at Sidi El Aydi, Khemis Zemamra and Jemaa Shaim but at Tessaout, Marzak and Karim showed significantly lower emergence rates than did Cocorit (Table 38). TBZ seed treatment resulted in significant increases in emergence in all varieties at all locations.

Seed inoculation significantly decreased straw yield for all varieties at Sidi El Aydi, for Marzak, Karim and Kyperounda at Jemaa Shaim, and for Kyperounda at Tessaout

(Table 39). TBZ had no effect on straw yield at Khemis Zemamra but significantly increased it for all varieties at Sidi El Aydi, for all except Cocorit at Jemaa Shaim, and for Kyperounda at Tessaout. Grain yield was significantly reduced in inoculated plots in all varieties at all locations (Table 40). At Khemis Zemamra this yield was not significantly different from zero for all treatments. Reduction in grain yield was statistically the same for all varieties at Jemaa Shaim and Tessaout but at Sidi El Aydi, Karim showed a greater reduction than Cocorit and Kyperounda while Marzak showed a greater reduction than Kyperounda. TBZ seed treatment gave significant grain yield increases at all locations except at Khemis Zemamra. At Sidi El Aydi, yield increase was greater for Marzak than that for Cocorit and Kyperounda, and yield increase for Karim was greater than that for Cocorit. At Jemaa Shaim, seed treatment did not affect Cocorit grain yield but caused significant increase in the other varieties with no difference between them. At Tessaout, all varieties had a similar significant grain yield increases with this treatment.

Table 37. Effect of Fusarium culmorum seed inoculation and Thiabendazole seed treatment on deadhead occurrence in four wheat varieties grown in two locations in West Central Morocco in 1986/87 season

| Locations and varieties | Inoculated[a] | | |
|---|---|---|---|
| | Untreated | Treated[b] | Difference[c] |
| Sidi El Aydi | | | |
| Cocorit | 57.7[d] | 3.3 | 54.4 ** |
| Marzak | 44.0 | 5.3 | 38.7 ** |
| Karim | 31.0 | 5.3 | 25.7 ** |
| Kyperounda | 15.7 | 1.7 | 14.0 ** |
| LSD 0.05[e] | 8.2 | 8.2 | 11.6 |
| Mean | 37.0 | | |
| Tessaout | | | |
| Cocorit | 26.0 | 8.3 | 17.7 |
| Marzak | 32.3 | 6.0 | 26.3 |
| Karim | 18.0 | 0.7 | 17.3 |
| Kyperounda | 45.0 | 2.3 | 42.7 ** |
| LSD 0.05[e] | 19.4 | 19.4 | 27.5 |
| Mean | 30.3 | | |

[a]Seed inoculated with a spore suspension of F. culmorum.

[b]Seed treated with Thiabendazole at the rate of 100 g a.i. /100 kg seed.

[c]Contrasts between treatment means significant at *= P= 0.05, **= P= 0.01 (Appendix Table A16).

[d]% deadhead evaluated at wheat Feekes' growth stage 11.1 with a deadhead= tiller prematurely ripened with a bleached ear appearing white in a field otherwise green.

[e]ANOVA summary in Appendix Table A16.

Table 38. Effect of Fusarium culmorum seed inoculation and Thiabendazole seed treatment on seedling emergence of four wheat varieties grown in four locations in West Central Morocco in 1986/87 season

| Locations and varieties | Inoculated[a] | | |
|---|---|---|---|
| | Untreated | Treated[b] | Difference[c] |
| Sidi El Aydi | | | |
| Cocorit | 21.3[d] | 94.3 | 73.0 ** |
| Marzak | 3.3 | 119.0 | 115.7 ** |
| Karim | 3.0 | 108.3 | 105.3 ** |
| Kyperounda | 4.7 | 148.3 | 143.6 ** |
| LSD 0.05[e] | 18.1 | 18.1 | 25.6 |
| Khemis Zemamra | | | |
| Cocorit | 37.3 | 108.0 | 70.7 ** |
| Marzak | 13.3 | 127.7 | 114.4 ** |
| Karim | 12.3 | 135.0 | 122.7 ** |
| Kyperounda | 19.0 | 115.7 | 96.7 ** |
| LSD 0.05[e] | 32.0 | 32.0 | 45.3 |
| Jemaa Shaim | | | |
| Cocorit | 16.3 | 115.7 | 99.4 ** |
| Marzak | 5.7 | 104.7 | 99.0 ** |
| Karim | 6.3 | 154.0 | 147.7 ** |
| Kyperounda | 8.7 | 165.7 | 157.0 ** |
| LSD 0.05[e] | 33.9 | 33.9 | 47.9 |
| Tessaout | | | |
| Cocorit | 45.7 | 89.0 | 43.3 ** |
| Marzak | 19.7 | 94.3 | 74.6 ** |
| Karim | 20.7 | 95.3 | 74.6 ** |
| Kyperounda | 29.0 | 111.3 | 82.3 ** |
| LSD 0.05[e] | 23.4 | 23.5 | 32.2 |

[a]Seed inoculated with a spore suspension of F. culmorum.

[b]Seed treated with Thiabendazole at the rate of 100 g a.i./100 kg seed.

[c]Contrasts between treatment means significant at *= P= 0.05, **= P= 0.01 (Appendix Table A17).

[d]Emergence in number of plants/$m^2$ evaluated at Feekes' growth stages 1-3.

[e]ANOVA summary in Appendix Table A17.

Table 39. Effect of Fusarium culmorum seed inoculation and Thiabendazole seed treatment on straw yield of four wheat varieties grown in four locations in West Central Morocco in 1986/87 season

| Locations and varieties | Inoculated[a] | | |
|---|---|---|---|
| | Untreated | Treated[b] | Difference[c] |
| Sidi El Aydi | | | |
| Cocorit | 11.2[d] | 17.4 | 6.2 ** |
| Marzak | 1.7 | 18.2 | 16.5 ** |
| Karim | 2.3 | 18.7 | 16.4 ** |
| Kyperounda | 4.0 | 26.0 | 22.0 ** |
| LSD 0.05[e] | 3.9 | 3.9 | 5.5 |
| Khemis Zemamra | | | |
| Cocorit | 5.6 | 5.2 | -0.4 |
| Marzak | 1.6 | 3.6 | 2.0 |
| Karim | 2.6 | 4.6 | 2.0 |
| Kyperounda | 1.8 | 4.8 | 3.0 |
| LSD 0.05[e] | 3.7 | 3.7 | 5.2 |
| Jemaa Shaim | | | |
| Cocorit | 6.2 | 8.8 | 2.6 |
| Marzak | 2.8 | 11.7 | 8.9 ** |
| Karim | 2.5 | 8.6 | 6.1 * |
| Kyperounda | 3.1 | 10.7 | 7.6 ** |
| LSD 0.05[e] | 5.1 | 5.1 | 7.3 |
| Tessaout | | | |
| Cocorit | 17.1 | 23.4 | 6.3 |
| Marzak | 10.5 | 22.0 | 11.5 |
| Karim | 12.4 | 17.0 | 4.6 |
| Kyperounda | 14.8 | 30.2 | 15.4 * |
| LSD 0.05[e] | 12.9 | 12.9 | 18.3 |

[a]Seed inoculated with a spore suspension of F. culmorum.

[b]100 g a.i./100 kg seed.

[c]Contrasts between treatment means significant at *= P= 0.05, **= P= 0.01 (Appendix Table A18).

[d]Straw yield in qx/ha.

[e]ANOVA summary in Appendix Table A18.

Table 40. Effect of Fusarium culmorum seed inoculation and Thiabendazole seed treatment on grain yield of four wheat varieties grown in four locations in West Central Morocco in 1986/87 season

| Locations and varieties | Inoculated[a] | | |
|---|---|---|---|
| | Untreated | Treated[b] | Difference[c] |
| Sidi El Aydi | | | |
| Cocorit | 2.1[d] | 7.8 | 5.7** |
| Marzak | 0.2 | 10.6 | 10.4** |
| Karim | 0.4 | 9.4 | 9.0** |
| Kyperounda | 0.3 | 6.9 | 6.6** |
| LSD 0.05[e] | 2.4 | 2.4 | |
| Khemis Zemamra | | | |
| Cocorit | 0.4 | 0.4 | 0.0 |
| Marzak | 0.1 | 0.4 | 0.3 |
| Karim | 0.4 | 0.4 | 0.0 |
| Kyperounda | 0.1 | 0.3 | 0.2 |
| LSD 0.05[e] | 0.5 | 0.5 | 0.8 |
| Jemaa Shaim | | | |
| Cocorit | 1.5 | 3.8 | 2.3 |
| Marzak | 0.4 | 6.0 | 5.6 ** |
| Karim | 0.3 | 5.0 | 4.7 ** |
| Kyperounda | 0.3 | 4.4 | 4.1 ** |
| LSD 0.05[e] | 2.7 | 2.7 | 3.9 |
| Tessaout | | | |
| Cocorit | 5.1 | 11.5 | 6.4 * |
| Marzak | 2.3 | 11.0 | 8.7 * |
| Karim | 3.0 | 10.8 | 7.8 * |
| Kyperounda | 2.0 | 9.3 | 7.3 * |
| LSD 0.05[e] | 6.9 | 6.9 | 9.7 |

[a]Seed inoculated with a spore suspension of F. culmorum.

[b]Seed treated with Thiabendazole at the rate of 100 g a.i. /100 kg.

[c]Contrasts between treatment means significant at *= P= 0.05, **= P= 0.01 (Appendix Table A19).

[d]Grain yield in qx/ha.

[e]ANOVA summary in Appendix Table A19.

# DISCUSSION

Surveys of wheat fields showing maximum root rot severity indices of 20 and 25% and mean indices of 7.2 and 10.8% in 1985/86 and 1986/87, respectively, indicate that root rot, although encountered in almost avery field, occurs at low severities in the West Central region of Morocco. This was further substantiated by the fact that 91.2% of all the plants examined had a root rot rating of 1, in which only small scattered lesions were observed on roots or subcrown internodes. Under similar climatic conditions in eastern Australia, Burgess et al. (1975) reported that 22.7% of fields had crown rot symptoms with 3% and 1% of these fields showing 1% and 5-20% deadheads respectively.

Yield losses, as estimated by the correlation coefficient of -0.56 (average of 8 tests) between root rot index (as used in the present study) and grain yield in wheat (Greaney et al., 1938), were 4.0 and 6.0% in West Central Morocco in 1985/86 and 1986/87 respectively. These values are similar to the 5-7% yield loss reported from the Canadian prairies (Ledingham et al., 1973) but smaller than the 50% recorded in some wheat fields in the Pacific Northwest U.S.A. (Cook, 1968b).

The most prevalent fungi associated with root rot symptoms over the two growing seasons were H. sativum (isolated from 88.1% of the fields), F. equiseti (47%), F. culmorum (24.4%), F. oxysporum (18%), and F. solani (12.5%). The predominance of H. sativum is not unique to West Central Morocco. Surveys carried out elsewhere indicated this fungus to be the most prevalent in Pennsylvania (Broscious and Frank, 1986), western Canada (Tinline, 1986; Ledingham, 1961; Broadfoot, 1934b), and Brazil (Diehl, 1979). This was not the case, however, in the Pacific Northwest U.S.A. (Cook, 1968b), southern Italy (Piglionica et al., 1975), the Paris area of France (Cassini, 1967), Poland (Manka et al., 1985), and England (Snyder and Nash, 1968; Colhoun and Park, 1964; Russell, 1932; Bennett, 1928) where F. culmorum prevailed. Also reports from New York (Kane et al., 1987), Australia (Wearing and Burgess, 1977; Burgess et al., 1975), southern France (Cassini, 1967), Queensland (McNight and Hart, 1966), Minnesota (Warren and Kommedahl, 1973), and California (Oswald, 1950) indicated that F. graminearum was predominant in these regions. In the present study F. culmorum, was not as widespread as H. sativum but still was present in nearly 25% of the fields. This frequency of F. culmorum was greater than that found in eastern Australia (Burgess et al., 1975) and in Victoria, Australia (Chambers, 1972) but less than

that in southern Italy (Piglionica et al., 1975). Cook (1968b) reported only trace amounts of plant infection by F. culmorum in the Pacific Northwest U.S. Over the two seasons of the study, F. culmorum and H. sativum were the most frequent fungi associated with root rot symptoms in diseased plants with rot ratings of 3 and 4. When tested on wheat varieties, both fungi caused root rot although F. culmorum consistently caused more damage to wheat plants than H. sativum. It was concluded, therefore, that these pathogens are the most virulent root rot pathogens under the climatic conditions of West Central Morocco.

Soil surveys revealed F. equiseti as the most prevalent fungus in West Central Morocco (isolated from 98% of the fields), followed by F. solani (52%), F. oxysporum (38.3%). Of the pathogenic species found, F. culmorum, F. graminearum, and F. avenaceum were recorded in 5.3, 1.1, and 1.9% fields respectively. In general, the Fusarium species isolated from soil were those known to be associated with wheat crop worldwide (Warren and Kommedahl, 1973; Nyvall, 1969; Snyder and Nash, 1968; Gordon, 1956). Surveys carried out in eastern Australia reported F. graminearum to be present in 30.6% fields but F. culmorum and F. avenaceum were absent (Wearing and Burgess, 1977). In the Pacific Northwest U.S.A., F. culmorum was isolated from 27.5% fields and F.

graminearum was not recovered (Cook, 1968b).

Comparisons between isolation frequencies of pathogenic Fusarium species from plants and soils clearly indicate that F. culmorum, F. avenaceum, and F. graminearum were more frequently isolated from diseased plants than they were recovered from soils. The soil dilution technique, used in this study, underestimated the prevalence of these fungi. A similar problem with this technique was reported for F. graminearum in eastern Australian soils (Wearing and Burgess, 1977). Although H. sativum inoculum in soil was not measured, the fact that this fungus was isolated from diseased plants in 98% of the field suggest that it is a common soil-borne fungus in West Central Morocco.

The seed survey indicated that F. equiseti was the most prevalent fungus of the genus on wheat seed (21.4% of seed samples). Root rot pathogens found on seed were F. culmorum (2.3%), F. graminearum (0.5%), and H. sativum (0.5%). Fusarium species recorded on seed in the present study also have been reported on seed in Finland (Uoti and Ylimaki, 1974), Canada (Gordon, 1952, 1944), England (Hewett, 1967), Victoria, Australia (Chambers, 1972) and Morocco (Lyamani, 1975). Under the similar climatic conditions of Australia, Chambers (1972) reported F. avenaceum, F. culmorum, F. equiseti, F. poae and F. trichothecioides from seedlots of

wheat in Victoria with 8% of seed samples infected. In Canada, Gordon (1952) reported F. equiseti, F. poae, F. scirpi and F. acuminatum as the most prevalent and of all seed examined less than 1% showed Fusarium spp. infection. In England, Hewett (1967) found F. avenaceum and F. poae as the most frequently found fungi (50% seed samples) with average seed infection values of 1-1.5% and 1-2% respectively. In general, reports from low rainfall areas have shown that pathogenic Fusarium species occur at low frequencies on seed. In areas of high rainfall, however, these frequencies are higher. In Mid-Atlantic region of U.S.A. (Halfon-Meiri et al., 1979) and New York state (Crosier and Waters, 1959), for example, an average 18% seed infection and 65% seed samples were infected with F. graminearum respectively.

A major objective of this study was to evaluate the relative importance of seed and soil as sources of inoculum for root rot pathogens. Inoculum of both F. culmorum and H. sativum, when applied to soil did not affect germination but did cause root rot which increased in severity as growth stages progressed and reduced grain yield.

Natural infection levels of F. culmorum of 1 to 8% infected seed did not affect root rot severity in field plots. This indicated that naturally occurring seed

infection levels of this fungus had no role in the epidemiology of the disease. This is in agreement with a similar conclusion reached by Cassini (1970) and De Tempe (1958). On the other hand, when seedlots were inoculated with F. culmorum to infection levels of 80 to 100%, severe root rot and drastic reduction in plant emergence and crop yield resulted. These striking effects of the artificial inoculation suggest that seed-borne inoculum, when present at high levels, can cause severe damage to wheat plants.

Row spacing of 20, 40 and 60 cm were included in this study to investigate whether, under West Central Morocco conditions, plant density could be used to reduce root rot. In general, the high plant density (row spacing of 20 cm) tended to increase root rot and deadhead incidence in a cropping season with adequate rainfall (1985/86). In the dry 1986/87 season, however, all plots were stressed and row spacing had no effect. Other conflicting results on effects of planting density on wheat root rot have been reported. Broscious and Frank (1986) and Tinline (1986) did not find any effect of plant density on root rot, while Papendick and Cook (1974) and Greaney (1946) reported that root rot severity increased with planting density.

In this study, seed vigor of wheat showed no effect on root rot development and yields. An opposite conclusion was

reached by Machacek and Greaney (1936, 1933) and Mesterhazy (1983) who reported that plants grown from low vigor seed were more susceptible to root rot than those grown from high vigor seed.

Thiabendazole (TBZ) seed treatment effectively eradicated seed-borne inoculum of F. culmorum and improved emergence of all seedlots. It also controlled root rot in plots planted with seed inoculated with this fungus, improved seedling emergence, and increased straw and grain yields. Similar success in eradicating Fusarium species from seed, was reported by Martin and Johnston (1982) with Benomyl+ Thiram and Cassini (1970) with Thiabendazole. In another seed treatment study, however, McNight and Hart (1966) did not increase yield under field conditions with mercurial, copper carbonate and hexachlorobenzene fungicides in wheat plots where 20% deadhead were observed.

The occurrence of root rot and deadhead in plots planted with Thiabendazole treated seeds and the isolation of F. culmorum from diseased plants in these plots, indicated the presence of this pathogen in soils at all experimental sites. Khemis Zemamra appeared to have the highest level of this inoculum, Tessaout had approximately half of that level, and the other two locations had low levels. The fact that TBZ seed treatment did reduce root rot severity in plots planted

with treated uninoculated seed at Khemis Zemamra only, suggest that TBZ had an effect on the soil-borne inoculum of this fungus.

The varieties used in this study showed significant differences in their reaction to inoculation by H. sativum and F. culmorum. Cocorit was highly susceptible to F. culmorum as indicated by high root rot severities % deadhead, and drastic reductions in emergence and straw and grain yields. This variety was, however, slightly susceptible to H. sativum as indicated by intermediate levels of root rot, but had substantial reductions in emergence and straw yield. Kyperounda was moderately susceptible, overall, to both H. sativum and F. culmorum. Marzak and Karim were also moderately susceptible to F. culmorum and fairly resistant to H. sativum. In West Central Morocco, Kyperounda is widely grown and its moderate susceptibility to these common root rot pathogens may account for the low severities of root rot in the region. Differences in varietal response to root rot pathogens were also reported by others (Piglionica et al., 1975; Statler and Darlington, 1972; Kommedahl and Patel, 1966; Greaney et al., 1938; and Russell, 1932). Purss (1966) reported wheat varieties Gala and Mengavi showing a reasonable level of field tolerance to crown rot caused by F. graminearum. Verma (1983) in Canada, tested 3 varieties and

Cypress was the most susceptible to H. sativum root rot, Neepawa intermediate and 680-1 the least. Sallans and Tinline (1965) succeeded in selecting and breeding wheat resistant to common root rot caused by H. sativum.

The two cropping seasons of the study differed in both the annual rainfall and daily temperature. Well distributed and adequate moisture characterized the 1985/86 season while 1986/87 was drier and hotter with the cereal crop subjected more frequently to drought stress. Field surveys showed higher root rot severity indices, greater numbers of plants with rot ratings of 3 and 4, and greater root rot incidences in the dryer season. In the field experiment root rot severities, and % deadhead were greater and plant emergence, straw and grain yields consistently smaller in the 1986/87 season than wetter 1985/86 season. Also in the 1986/87 season, H. sativum and F. culmorum caused greater root rot severities and crop losses. These findings indicate that dryer and hot climatic conditions of 1986/87 enhanced the ability of root rot pathogens to cause disease and reduce the productivity of wheat crop. The enhancing effect of low soil moisture on root rot complex is consistent with the observations under field conditions of Burgess et al. (1975), Cook (1968b), and McNight and Hart (1966) and with those made in controlled soil moisture studies by others (Cassell and

Hering, 1982; Cook, 1973; Cook et al., 1972; Colhoun et al., 1968; Dickson, 1923).

The present study covered several important aspects of root rot of wheat in West Central Morocco. Major conclusions are: 1) root rot is a common disease in West Central Morocco; 2) Helminthosporium sativum and Fusarium culmorum are the major causal agents of wheat root rot; 3) soil is the major source of inoculum for these two pathogens; 4) F. culmorum soil-borne inoculum does not affect germination but can cause root rot and reduced grain yield; 5) high levels of F. culmorum seed-borne inoculum caused severe root rot and reduced drastically seedling emergence and crop yield; 6) low levels of natural seed infection by H. sativum and F. culmorum, the planting density, and seed vigor had no significant effects in the epidemiology of the disease; 7) of four commonly grown wheat varieties, Cocorit is very susceptible to F. culmorum and slightly susceptible to H. sativum, Kyperounda is moderately susceptible to both pathogens, and Marzak and Karim are moderately susceptible to F. culmorum but fairly resistant to H. sativum; 8) Thiabendazole seed treatment is effective against F. culmorum seed infection and can, to some extent, reduce infections from soil-borne inoculum of this fungus.

Although root rot caused relatively minor losses in West Central Morocco, these are not insignificant, particularly in dry years. Control measures, therefore, seem justified. Of these, the most promising approaches in future work would be to breed for resistance to both H. sativum and F. culmorum, and also to obtain seed treatment fungicides with a good ability to control soil-borne inoculum of H. sativum and Fusarium spp.

# SUMMARY AND CONCLUSIONS

Surveys of wheat fields in West Central Morocco showed average root rot incidences of 7.2 and 10.8%, and yield losses of 4 and 6% in 1985/86 and 1986/87 respectively. The most prevalent fungi associated with root rot symptoms were Helminthosporium sativum, Fusarium equiseti, F. culmorum, F. oxysporum, and F. solani. Of these, F. culmorum and H. sativum are recognized as the most frequent pathogenic fungi of wheat. Fusarium equiseti was the most prevalent soil Fusarium species in West Central Morocco, followed by F. solani, and F. oxysporum. Pathogenic species, including F. culmorum, F. graminearum, and F. avenaceum were found in only a few fields. Fusarium equiseti was again the most prevalent Fusarium species on wheat seed. Fusarium culmorum, F. graminearum, and H. sativum were also found on seed but at low frequencies.

The relative importance of seed and soil as sources of inoculum for root rot pathogens was investigated. Soil-borne inoculum of both F. culmorum and H. sativum did not affect germination but did cause root rot and reduced grain yield. Fusarium culmorum natural seed infection occurred at low levels (1 to 8% seed infection) and did not affect root rot severity. Artificially applied seed-borne inoculum of this

fungus, however, caused severe root rot and drastic reduction in plant emergence and crop yield.

In considering factors that affect wheat root rot under West Central Morocco conditions, high planting density (row spacing of 20 cm) tended to increase root rot and deadhead incidence in a cropping season with adequate rainfall (1985/86). Seed vigor, however, had no effect on root rot development and crop yield. Thiabendazole (TBZ) seed treatment effectively eradicated seed-borne inoculum of F. culmorum; controlled root rot and improved seedling emergence, straw and grain yields. The four varieties tested in this study showed significant differences in their reaction to inoculation by H. sativum and F. culmorum. Cocorit was highly susceptible to F. culmorum and slightly susceptible to H. sativum. Kyperounda was moderately susceptible to both H. sativum and F. culmorum. Marzak and Karim were moderately susceptible to F. culmorum and fairly resistant to H. sativum.

The 1985/86 season was characterized by well distributed and adequate moisture, while the 1986/87 was drier and hotter. Higher root rot incidence and severity, and greater crop losses were detected in surveys and field experiments in 1986/87 season than in the wetter 1985/86 season.

The major conclusions of this study are: 1) root rot is a common disease of wheat in West Central Morocco; 2) Helmnithosporium sativum and Fusarium culmorum are the major causal agents of wheat root rot; 3) soil is the major source of inoculum for these two pathogens; 4) Fusarium culmorum soil-borne inoculum did not affect seedling emergence but induced root rot and reduced grain yield; 5) Fusarium culmorum seed-borne inoculum when present at high concentration levels caused severe root rot and reduced seedling emergence and crop yield; 6) low levels of F. culmorum naturally occurring seed infection, planting density, and seed vigor have no significant role in the epidemiology of the disease; 7) wheat varieties varied in susceptibility to root infection by F. culmorum and H. sativum; 8) Thiabendazole seed treatment is effective against F. culmorum seed infection and can, to some extent, reduce infections from soil-borne inoculum of this fungus.

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## ACKNOWLEDGEMENTS

I extend my special thanks to my major professor, Dr. Denis C. McGee for his time, encouragement, and support. His help and that of his wife Judy made the stay in Ames for me and my family pleasant, enjoyable and fruitful. Working with Denis has been very much a pleasure and a privilege.

I have very much appreciated the help of the other members of my graduate Committee, Dr. J. M. Dunleavy, Dr. M. K. Misra, Dr. R. Mullen, Dr. R. F. Nyvall, and Dr. L. Tiffany. Their help and guidance throughout my graduate studies at ISU have contributed to this excellent learning experience.

My special thank-you to my wife, Latifa and my daughters Hakima and Nezha. They have been supportive all the time, patient and wonderful.

I would like to express my gratitude to INRA Director, Houcin Faraj for allowing me to join this training program and to US-AID for the financial support made available through INRA/ MIAC Dryland Farming Project No 608-0136.

I am indebted to Dr. P. E. Nelson, The Fusarium Center, Pennsylvania State University, for identifying Fusarium isolates I collected in my surveys.

My thanks to all my friends at the Aridoculture Center, Settat, Morocco; especially Mohamed El Mourid, Mohamed El Yamani, and Mohamed Derkaoui. Their presence along with their families in Settat has been of great help to me and my family.

My sincere thanks to Dr. J. P. Jones, Mohamed Marah, Fatna El-Ajouad and Abdelhaq Khabouz for their assistance and well-timed help; and to Cathy Kourriri for typing the first manuscript of this dissertation.

# APPENDIX

Table A1. Mean square and F-ratio for root rot severity index and % deadhead data for 1985/86 field experiment 1

| Source of variation | DF | Root rot severity at FGS[a] 8-9 MS | 8-9 F | 10.5.3 MS | 10.5.3 F | % Deadhead MS | % Deadhead F |
|---|---|---|---|---|---|---|---|
| Blocks | 3 | 98.8 | | 174.4 | | 10.4 | |
| RS[b] | 2 | 102.0 | 1.9 | 16.3 | 0.1 | 24.4 | 5.4* |
| IS[c] | 1 | 2911.1 | 54.6** | 5970.7 | 47.8** | 33.7 | 7.5* |
| RS x IS | 2 | 15.9 | 0.3 | 222.0 | 1.8 | 0.1 | 0.0 |
| Error | 15 | 53.4 | | 124.9 | | | |

[a]FGS= Feekes' growth stage.

[b]Row spacing= 20, 40, and 60 cm.

[c]Inoculum source: 1= uninoculated, 2= soil inoculation with F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A2. Mean square and F-ratio for root rot severity index and % deadhead data for 1986/87 field experiment 1

| Source of variation | DF | Root rot severity at FGS[a] 8-9 MS | 8-9 F | 10.5.3 MS | 10.5.3 F | % Deadhead MS | % Deadhead F |
|---|---|---|---|---|---|---|---|
| Blocks | 3 | 136.8 | | 412.2 | | 75.8 | |
| RS[b] | 2 | 41.2 | 1.0 | 45.5 | 0.4 | 87.5 | 2.3 |
| IS[c] | 3 | 1652.9 | 38.0** | 628.5 | 5.0** | 195.4 | 5.0** |
| RS x IS | 6 | 93.2 | 2.1 | 733.6 | 5.8** | 106.4 | 2.7 |
| Error | 33 | 43.5 | | 126.5 | | 38.8 | |

[a]FGS= Feekes' growth stage.

[b]Row spacing= 20, 40, and 60 cm.

[c]Inoculum source: 1= uninoculated, 2= soil inoculation, 3= seed inoculation, and 4= seed and soil inoculation with F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A3. Mean square and F-ratio for seedling emergence data of 1985/86 field experiment 1

| Source of variation | DF | Emergence | |
|---|---|---|---|
| | | MS | F |
| Blocks | 3 | 3.9 | |
| Row spacing (RS)[a] | 2 | 11606.2 | 413.1** |
| Inoculum source (IS)[b] | 3 | 28414.7 | 1011.5* |
| RS x IS | 6 | 3021.9 | 107.6* |
| Error | 33 | 28.1 | |

[a]Row spacing= 20, 40, and 60 cm.

[b]Inoculum source: 1= uninoculated, 2= soil inoculation, 3= seed inoculation, and 4= seed and soil inoculation with F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A4. Mean square and F-ratio for yield data of 1985/86 field experiment 1

| Source of variation | DF | Straw yield | | Grain yield | |
|---|---|---|---|---|---|
| | | MS | F | MS | F |
| Blocks | 3 | 68.4 | | 84.2 | |
| Row spacing (RS)[a] | 2 | 512.7 | 44.1** | 8.8 | 0.5 |
| Inoculum source (IS)[b] | 1 | 2.2 | 0.2 | 244.0 | 14.0** |
| RS x IS | 2 | 4.1 | 0.4 | 17.1 | 0.0 |
| Error | 15 | 11.6 | | 17.5 | |

[a]Row spacing= 20, 40, and 60 cm.

[b]Inoculum source: 1= uninoculated,2= soil inoculation with F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A5. Mean square and F-ratio for seedling emergence and yield data of 1986/87 field experiment 1

| Source of variation | DF | Emergence | | Straw yield | | Grain yield | |
|---|---|---|---|---|---|---|---|
| | | MS | F | MS | F | MS | F |
| Blocks | 3 | 9.0 | | 24.3 | | 0.4 | |
| RS[a] | 2 | 9521.0 | 623.2** | 378.9 | 24.7** | 52.5 | 36.7** |
| IS[b] | 3 | 12700.0 | 831.2** | 555.8 | 36.3** | 104.0 | 72.6** |
| RS x IS | 6 | 1399.6 | 91.6** | 10.2 | 0.7 | 3.0 | 2.1 |
| Error | 33 | 15.3 | | 15.3 | | 1.4 | |

[a]Row spacing: 20, 40, and 60 cm.

[b]Inoculum source: 1= uninoculated, 2= soil inoculation, 3= seed inoculation, and 4= seed and soil inoculation with F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A6. Mean square and F-ratio for root rot severity index and % deadhead of 1985/86 field experiment 2

| Source of variation | DF[b] | Root rot severity at FGS[a] 8-9 MS | 8-9 F | 10.5.3 MS | 10.5.3 F | % Deadhead MS | % Deadhead F |
|---|---|---|---|---|---|---|---|
| Blocks | 3 | 386.8 | | 353.3 | | 1585.6 | |
| RS[c] | 2 | 763.7 | 11.1** | 1124.9 | 3.6 | 1092.7 | 6.3* |
| Error (a) | 6 | 68.7 | | 312.6 | | 172.9 | |
| SV[d] | 3 | 25.2 | 0.2 | 81.4 | 0.5 | 46.7 | 1.3 |
| RS x SV | 6 | 208.4 | 1.5 | 125.9 | 0.8 | 54.6 | 1.5 |
| Error (b) | 27 | 142.1 | | 159.8 | | 34.0 | |

[a]FGS= Feekes' growth stage.

[b]Error term for RS= error(a), SV and RS X SV= error(b).

[c]Row spacing= 20, 40, and 60 cm.

[d]Seed vigor= 17.6, 15.9, 10.6, and 9.9 mg/seedling.

*Significant at the level of 0.05 probability.

**Significant at the level of 0.01 probability.

Table A7. Mean square and F-ratio for root rot severity index and % deadhead of 1986/87 field experiment 2

| Source of variation | DF[b] | Root rot severity at FGS[a] 8-9 MS | 8-9 F | 10.5.3 MS | 10.5.3 F | % Deadhead MS | % Deadhead F |
|---|---|---|---|---|---|---|---|
| Blocks | 3 | 112.3 | | 443.9 | | 411.1 | |
| RS[c] | 2 | 0.3 | 0.0 | 45.3 | 0.3 | 2067.8 | 11.5** |
| Error (a) | 6 | 216.5 | | 141.3 | | 179.2 | |
| SV[d] | 3 | 46.5 | 0.6 | 97.2 | 0.3 | 17.5 | 0.4 |
| RS x SV | 6 | 87.3 | 1.0 | 223.0 | 0.8 | 56.2 | 1.3 |
| Error (b) | 27 | 82.8 | | 294.7 | | 44.2 | |

[a]FGS= Feekes' growth stage.

[b]Error term for RS= error(a), SV and RS X SV= error(b).

[c]Row spacing= 20, 40, and 60 cm.

[d]Seed vigor= 17.6, 15.9, 10.6, and 9.9 mg/seedling.

*Significant at the level of 0.05 probability.

**Significant at the level of 0.01 probability.

Table A8. Mean square and F-ratio for seedling emergence and yield data of 1985/86 Field experiment 2

| Source of variation | DF[a] | Emergence | | Straw yield | | Grain yield | |
|---|---|---|---|---|---|---|---|
| | | MS | F | MS | F | MS | F |
| Blocks | 3 | 145.8 | | 289.3 | | 37.2 | |
| RS[b] | 2 | 42044.7 | 889.0** | 238.7 | 11.6** | 5.6 | 3.1 |
| Error (a) | 6 | 47.3 | | 20.6 | | 1.8 | |
| SV[c] | 3 | 1267.2 | 10.7** | 85.8 | 5.0** | 13.5 | 5.6** |
| RS X SV | 6 | 82.1 | 0.7 | 7.3 | 0.4 | 5.1 | 2.1 |
| Error (b) | 27 | 118.8 | | 17.0 | | 2.4 | |

[a]Error term for Row spacing= error(a), Seed vigor and RS X SV= error(b).

[b]Row spacing= 20, 40, and 60 cm.

[c]Seed vigor= 17.6, 15.9, 10.6, and 9.9 mg/seedling.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A9. Mean square and F-ratio for seedling emergence and yield data of 1986/87 field experiment 2

| Source of variation | DF[a] | Emergence | | Straw yield | | Grain yield | |
|---|---|---|---|---|---|---|---|
| | | MS | F | MS | F | MS | F |
| Blocks | 3 | 494.4 | | 147.2 | | 5.3 | |
| RS[b] | 2 | 45119.1 | 129.5** | 55.0 | 3.1 | 19.6 | 11.2** |
| Error (a) | 6 | 348.4 | | 18.0 | | 1.8 | |
| SV[c] | 3 | 898.8 | 12.3** | 4.7 | 0.5 | 0.1 | 0.1 |
| RS X SV | 6 | 238.7 | 3.3* | 6.9 | 0.9 | 0.7 | 0.5 |
| Error (b) | 27 | 73.3 | | 10.2 | | 1.4 | |

[a]Error term for Row spacing= error(a), Seed vigor and RS X SV= error(b).

[b]Row spacing= 20,40, and 60 cm.

[c]Seed vigor= 22.4, 20.0, 19.7, and 17.4 mg/seedling.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A10. Mean square (MS) and F-test for root rot severity index of 1986/87 field experiment 3

| Source of variation | DF[b] | Root rot severity index at FGS[a] 8-9 MS | 8-9 F | 10.5.3 MS | 10.5.3 F | 11.1 MS | 11.1 F |
|---|---|---|---|---|---|---|---|
| Block | 3 | 202.3 | 6.9** | 21.7 | 0.1 | 202.1 | 1.8 |
| V[c] | 3 | 297.8 | 10.1** | 6130.1 | 30.1** | 3716.8 | 32.5** |
| Error(a) | 9 | 29.4 | | 203.8 | | 114.4 | |
| RS[d] | 2 | 81.7 | 0.6 | 415.8 | 3.2 | 599.4 | 3.7* |
| V * RS | 6 | 73.6 | 0.6 | 0.8 | 0.7 | 105.3 | 0.7 |
| Error(b) | 24 | 130.7 | | 132.0 | | 160.1 | |
| P[e] | 2 | 4641.3 | 42.0** | 17540.0 | 155.2** | 24753.9 | 117.6** |
| V * P | 6 | 139.1 | 1.3 | 3283.7 | 29.5** | 887.7 | 4.2** |
| RS * P | 4 | 452.8 | 4.1** | 445.2 | 3.9** | 683.1 | 3.2* |
| V*RS*P | 12 | 87.3 | 0.6 | 146.6 | 1.3 | 154.3 | 0.7 |
| Error(c) | 72 | 110.5 | | 113.0 | | 210.5 | |

[a]FGS= Feekes' growth stage.

[b]Error term for V= error(a), RS and V X RS= error (b), P, P X RS, P X V, and P X RS X V= error (c).

[c]Variety 1= Cocorit, 2= Marzak, 3= Karim, and 4= Kyperounda.

[d]Row spacing= 20, 40, and 60 cm.

[e]Pathogen 1= uninoculated, 2= H. sativum, and 3= F. culmorum

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A11. Mean square (MS) and F-test for % deadhead data of 1986/87 field experiment 3

| Source of variation | DF[b] | % Deadhead[a] 1985/86 MS | 1985/86 F | 1986/87 MS | 1986/87 F |
|---|---|---|---|---|---|
| Block | 3 | 345.4 | 1.1 | 355.1 | 4.6* |
| Variety (V)[c] | 3 | 1213.4 | 3.8* | 3027.2 | 39.4 |
| Error (a) | 9 | 318.4 | | 76.8 | |
| Row spacing (RS)[d] | 2 | 1014.1 | 14.0** | 710.7 | 10.6** |
| V * RS | 6 | 160.9 | 2.2 | 734.5 | 11.0** |
| Error (b) | 24 | 72.2 | | 66.9 | |
| Pathogen (P)[e] | 2 | 2312.9 | 22.3** | 8358.8 | 73.8** |
| V * P | 6 | 254.1 | 2.4* | 1287.8 | 11.4** |
| RS * P | 4 | 322.9 | 3.1* | 1259.7 | 11.1** |
| V * RS * P | 12 | 81.8 | 0.8 | 471.7 | 4.2** |
| Error (c) | 72 | 103.9 | | 113.3 | |

[a]FGS= Feekes'growth stage.

[b]Error term for V= error(a), RS and V X RS= error (b), P, P X RS, P X V, and P X RS X V= error (c).

[c]Variety 1= cocorit, 2= Marzak, 3= Karim, and 4= Kyperounda.

[d]Row spacing= 20, 40, and 60 cm.

[e]Pathogen 1= uninoculated, 2= H. sativum, and 3= F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A12. Mean square (MS) and F-test for the % reduction in seedling emergence data of the 1985/86 and 1986/87 field experiment 3

| Source of variation | DF[a] | Emergence (% reduction) | | | |
|---|---|---|---|---|---|
| | | 1985/86 | | 1986/87 | |
| | | MS | F | MS | F |
| Block | 3 | 155.4 | 4.1* | 221.8 | 1.5 |
| Variety (V)[b] | 3 | 905.1 | 23.8** | 4145.7 | 27.1** |
| Error (a) | 9 | 38.0 | | 152.8 | |
| Row spacing(RS)[c] | 2 | 34.1 | 0.6 | 17.3 | 0.1 |
| V * RS | 6 | 86.5 | 1.4 | 60.4 | 0.4 |
| Error (b) | 24 | 61.6 | | 147.3 | |
| Pathogen (P)[d] | 1 | 85315.0 | 1692.8** | 82186.3 | 111.1** |
| V * P | 3 | 3741.6 | 74.2** | 996.5 | 13.4** |
| RS * P | 2 | 87.2 | 1.7 | 2.7 | 0.0 |
| V * RS * P | 6 | 46.6 | 0.9 | 19.5 | 0.3 |
| Error (c) | 36 | 50.4 | | 74.6 | |

[a]Error term for variety= error(a), Row spacing and V X RS= error (b), Pathogen, P X RS, P X V, P X RS X V= error(c).

[b]Variety 1= cocorit, 2= Marzak, 3= Karim, and 4= Kyperounda.

[c]Row spacing= 20, 40, and 60 cm.

[d]Pathogen 1= uninoculated, 2= H. sativum, and 3= F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A13. Mean square (MS) and F-test for the straw yield reduction data of the 1985/86 and 1986/87field experiment 3

| Source of variation | DF[a] | Straw yield (% reduction) 1985/86 MS | 1985/86 F | 1986/87 MS | 1986/87 F |
|---|---|---|---|---|---|
| Block | 3 | 351.3 | 0.8 | 1364.8 | 1.4 |
| Variety (V)[b] | 3 | 4409.3 | 10.4** | 6782.0 | 7.0** |
| Error (a) | 9 | 424.2 | | 968.4 | |
| Row spacing(RS)[c] | 2 | 1097.6 | 2.2 | 6530.2 | 4.6* |
| V * RS | 6 | 295.2 | 0.6 | 1159.4 | 0.8 |
| Error (b) | 24 | 500.6 | | 1404.9 | |
| Pathogen (P)[d] | 1 | 50500.0 | 229.3** | 45481.8 | 116.9** |
| V * P | 3 | 2601.5 | 11.8** | 3199.0 | 8.2** |
| RS * P | 2 | 872.2 | 4.0* | 802.2 | 2.1 |
| V * RS * P | 6 | 266.6 | 1.2 | 455.9 | 1.2 |
| Error (c) | 36 | 220.2 | | 389.1 | |

[a]Error term for variety= error(a), Row spacing and V X RS= error (b), Pathogen, P X RS, P X V, P X RS X V= error(c).

[b]Variety 1= cocorit, 2= Marzak, 3= Karim, and 4= Kyperounda.

[c]Row spacing= 20, 40, and 60 cm.

[d]Pathogen 1= uninoculated, 2= H. sativum, and 3= F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A14. Mean square (MS) and F-test for the grain yield reduction data of the 1985/86 and 1986/87 field experiment 3

| Source of variation | DF[a] | Grain yield (% reduction) 1985/86 MS | 1985/86 F | 1986/87 MS | 1986/87 F |
|---|---|---|---|---|---|
| Block | 3 | 237.5 | 0.5 | 6477.3 | 1.7 |
| Variety (V)[b] | 3 | 4757.5 | 9.9** | 3933.8 | 1.1 |
| Error (a) | 9 | 481.7 | | 3703.5 | |
| Row spacing (RS)[c] | 2 | 709.7 | 0.9 | 6631.2 | 2.7 |
| V * RS | 6 | 275.0 | 0.3 | 5136.9 | 2.1 |
| Error (b) | 24 | 831.8 | | 2473.0 | |
| Pathogen (P)[d] | 1 | 83352.4 | 323.2** | 72627.5 | 28.5** |
| V * P | 3 | 3478.0 | 13.5** | 4073.4 | 1.6 |
| RS * P | 2 | 307.9 | 1.2 | 1341.9 | 0.5 |
| V * RS * P | 6 | 210.8 | 0.8 | 4208.8 | 1.7 |
| Error (c) | 36 | 257.9 | | 2546.1 | |

[a]Error term for variety= error(a), Row spacing and V X RS= error (b), Pathogen, P X RS, P X V, P X RS X V= error(c).

[b]Variety 1= cocorit, 2= Marzak, 3= Karim, and 4= Kyperounda.

[c]Row spacing= 20, 40, and 60 cm.

[d]Pathogen 1= uninoculated, 2= H. sativum, and 3= F. culmorum.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A15. Mean square (MS) and F-test for root rot data of the 1986/87 field experiment 4

| Source of variation | DF | Location | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sidi El Aydi | | Khemis Zemamra | | Jemaa Shaim | | Tessaout | |
| | | MS | F | MS | F | MS | F | MS | F |
| Block | 1 | 12.7 | 0.7 | 8.1 | 0.3 | 55.8 | 2.0 | 126.6 | 2.0 |
| Treatment[a] | 31 | 615.7 | 35.8** | 93.3 | 3.8** | 339.3 | 11.9** | 305.1 | 4.8** |
| Inoculated untreated vs. treated | | | | | | | | | |
| Cocorit | 1 | 141.8 | 8.2* | 45.1 | 1.8 | 87.4 | 3.1 | 2624.2 | 41.1** |
| Marzak | 1 | 3587.3 | 208.4** | 67.7 | 2.7 | 1828.1 | 63.9** | 611.1 | 9.6** |
| Karim | 1 | 3135.5 | 182.2** | 857.5 | 34.6** | 1921.0 | 67.2** | 214.1 | 3.4** |
| Kyperounda | 1 | 3580.5 | 208.0** | 251.6 | 10.1** | 1123.7 | 39.3** | 1054.2 | 16.5** |
| Error | 62 | 17.2 | | 24.8 | | 28.6 | | 63.9 | |

[a]Treatment= 16 seedlots X 2 seed treatments (with or without Thiabendazole).

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A16. Mean square (MS) and F-test for the % deadhead data of the 1986/87 field experiment 4

| Source of variation | DF | Location | | | |
|---|---|---|---|---|---|
| | | Sidi El Aydi | | Tessaout | |
| | | MS | F | MS | F |
| Block | 2 | 46.3 | 1.8 | 990.4 | 7.0** |
| Treatment[a] | 31 | 447.3 | 17.8** | 264.3 | 1.9* |
| Inoculated untreated vs treated | | | | | |
| Cocorit | 1 | 4428.2 | 176.4** | 468.2 | 3.3 |
| Marzak | 1 | 2242.7 | 89.4** | 1040.2 | 7.3** |
| Karim | 1 | 988.2 | 39.4** | 450.7 | 3.2 |
| Kyperounda | 1 | 294.0 | 11.7** | 2730.7 | 19.2** |
| Error | 62 | 25.1 | | 142.1 | |

[a]Treatment= 16 seedlots X 2 seed treatments (with or without Thiabendazole).

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A17. Mean square (MS) and F-test for seedling emergence data of the 1986/87 fiel experiment 4

| Source of variation | DF | Location | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sidi El Aydi | | Khemis Zemamra | | Jemaa Shaim | | Tessaout | |
| | | MS | F | MS | F | MS | F | MS | F |
| Block | 2 | 7.0 | 0.1 | 614.3 | 1.6 | 1190.1 | 2.8 | 4802.5 | 23.2** |
| Treatment[a] | 31 | 4722.2 | 38.6** | 3756.5 | 9.7** | 6096.9 | 14.1** | 1894.4 | 9.2** |
| Inoculated untreated vs treated | | | | | | | | | |
| Cocorit | 1 | 7993.5 | 65.3** | 7490.7 | 19.4** | 14800.7 | 34.3** | 2816.7 | 13.6** |
| Marzak | 1 | 20068.2 | 164.0** | 19608.2 | 50.9** | 14701.5 | 34.1** | 8362.7 | 40.4** |
| Karim | 1 | 16642.7 | 136.0** | 22570.7 | 58.5** | 32708.2 | 75.9** | 8362.7 | 40.4** |
| Kyperounda | 1 | 30960.2 | 252.9** | 14016.7 | 36.4** | 36973.5 | 85.8** | 0168.2 | 49.1** |
| Error | 62 | 122.4 | | 385.5 | | 431.0 | | 206.9 | |

[a]Treatment= 16 seedlots X 2 seed treatments (with or without Thiabendazole).

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A18. Mean square (MS) and F-test for straw yield data of the 1986/87 field experiment 4

| Source of variation | DF | Location | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sidi El Aydi | | Khemis Zemamra | | Jemaa Shaim | | Tessaout | |
| | | MS | F | MS | F | MS | F | MS | F |
| Block | 2 | 275.1 | 49.1** | 47.5 | 9.5** | 173.7 | 17.5** | 1257.1 | 20.1 |
| Treatment[a] | 31 | 112.8 | 20.1** | 9.5 | 1.9* | 17.3 | 1.7* | 103.7 | 1.7* |
| Inoculated untreated vs treated | | | | | | | | | |
| Cocorit | 1 | 57.7 | 10.3** | 0.2 | 0.0** | 9.9 | 1.0 | 61.1 | 1.0 |
| Marzak | 1 | 408.1 | 72.9** | 6.0 | 1.2** | 117.5 | 11.8** | 198.5 | 3.2 |
| Karim | 1 | 402.6 | 71.9** | 6.3 | 0.3** | 56.2 | 5.7* | 31.8 | 0.5 |
| Kyperounda | 1 | 724.0 | 129.3** | 12.9 | 2.6** | 85.1 | 8.6** | 353.0 | 5.6* |
| Error | 62 | 5.6 | | 5.0 | | 9.9 | | 62.6 | |

[a]Treatment= 16 seedlots X 2 seed treatments (with or without Thiabendazole)

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A19. Mean square (MS) and F-test for the grain yield data of the 1986/87 field experiment 4

| Source of variation | DF | Location | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sidi El Aydi | | Khemis Zemamra | | Jemaa Shaim | | Tessaout | |
| | | MS | F | MS | F | MS | F | MS | F |
| Block | 2 | 32.4 | 14.7** | 0.2 | 1.6 | 61.0 | 21.6** | 314.3 | 17.6** |
| Treatment[a] | 31 | 25.1 | 11.4** | 0.2 | 2.2** | 6.7 | 2.4** | 22.3 | 1.2 |
| Inoculated untreated vs treated | | | | | | | | | |
| Cocorit | 1 | 48.9 | 35.8** | 0.0 | 0.0 | 7.9 | 2.8 | 62.1 | 3.5 |
| Marzak | 1 | 161.6 | 73.5** | 0.1 | 1.1 | 47.3 | 16.7** | 111.8 | 6.2* |
| Karim | 1 | 121.5 | 55.2** | 0.0 | 0.0 | 33.1 | 11.7** | 91.9 | 5.1* |
| Kyperounda | 1 | 64.8 | 29.5** | 0.1 | 7.2** | 24.7 | 8.7** | 81.0 | 4.5* |
| Error | 62 | 2.2 | | 0.1 | | 2.8 | | 17.7 | |

[a]Treatment= 16 seedlots X 2 seed treatments (with or without Thiabendazole).

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.